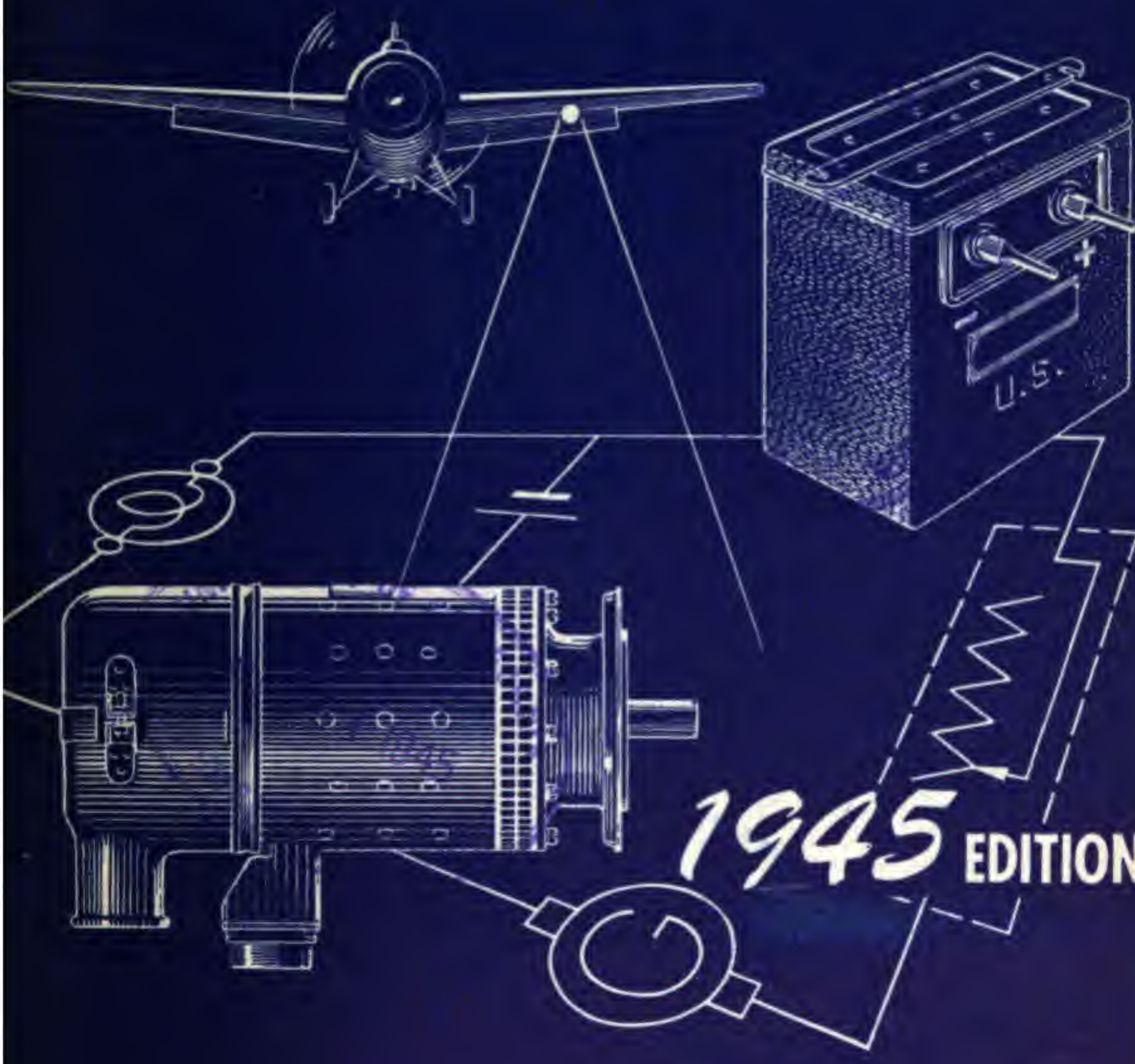
Aircraft

ELECTRICAL SYSTEMS



1945 EDITION

NAVY TRAINING COURSES

AIRCRAFT ELECTRICAL SYSTEMS

PREPARED BY
STANDARDS AND CURRICULUM DIVISION
TRAINING
US BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES
EDITION OF 1945

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1945

For sale by the Superintendent of Documents, Government Printing Office
Washington 25, D. C. - Price 35 cents

PREFACE

This book was written for the enlisted men of Naval Aviation. It is one of a series of books designed to give them the information necessary to perform their aviation duties.

A knowledge of aircraft electrical systems is of primary importance to Aviation Electrician's Mates. But other rates and other specialists will find it valuable background for their work. It will be helpful to Aviation Machinists Mates concerned with the electrical aspects of aircraft engine operation.

Beginning with basic information about aircraft wiring systems, this book proceeds with a discussion of starters, ignition, and spark plugs and ends with problems of aircraft power supply.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Naval Air Technical Training Command and the Training Courses Section of the Bureau of Naval Personnel.

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CHAPTER 1

WIRING SYSTEMS

LIGHTING

CLICK! You flip the switch from OFF to ON. But nothing happens. After 3 hours of struggling you have just FIXED the hall light so that it will work. Or have you? Suddenly you realize that you forgot to connect one of the wires to the terminal in the ceiling fixture, so you have to start all over again.

That sort of hit-and-miss system won't work in aviation. You have to be sure what you're doing. Every circuit in an airplane is important and each one must be perfect. In order to make correct installations you must be able to read the diagrams that indicate the circuit layouts.

So look at figure 1. These are some of the symbols which make up the language of electricity. It is possible that you have forgotten some of them. If that is the case, take a long look at them. Memorize those which give you trouble. Time spent now in learning them will assist you later on when YOU are called upon to do an important job. You can make NO mistakes on the job. Too much depends on your knowledge and skill. You must know WHAT to do and HOW to do it.

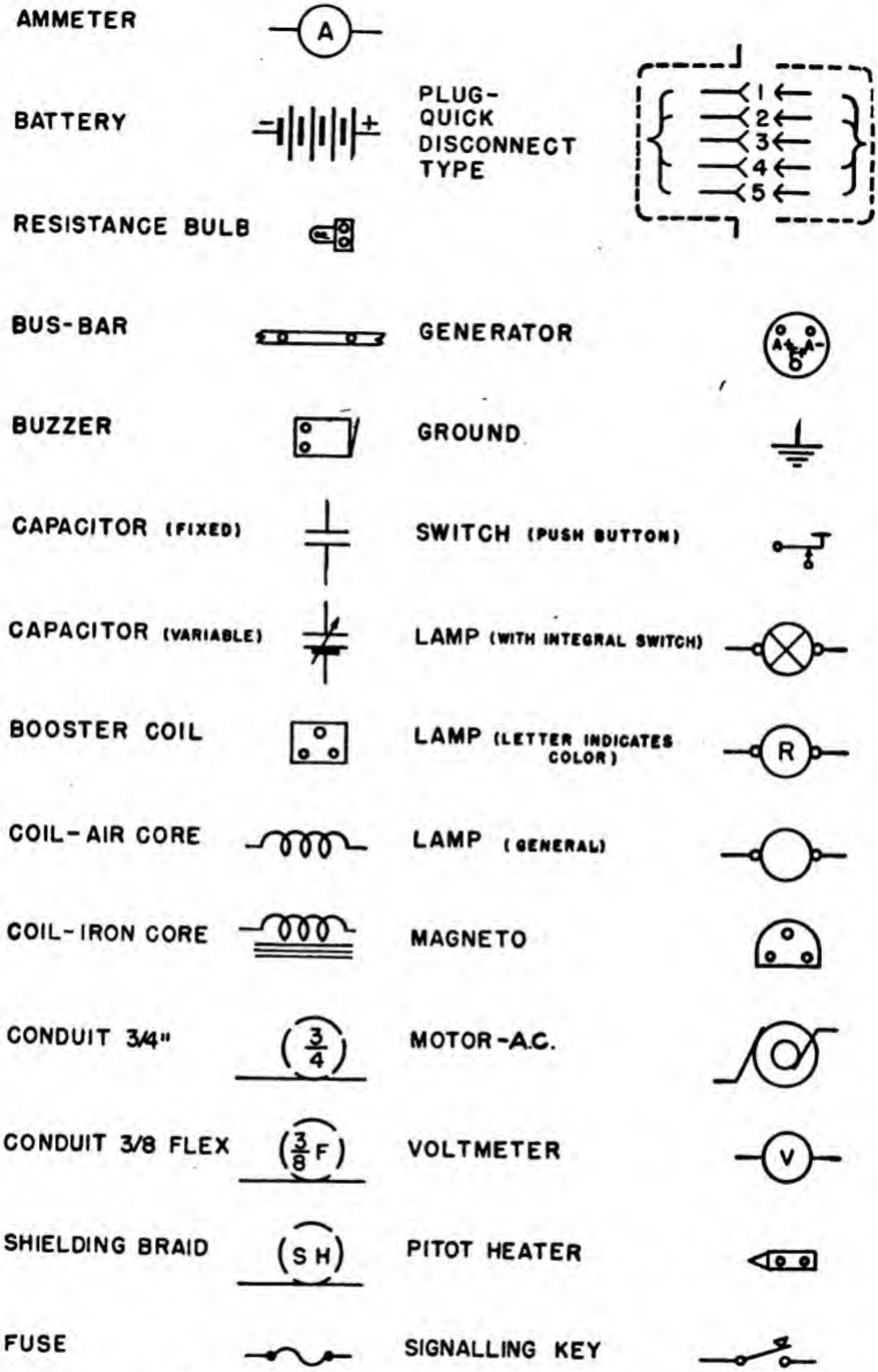


Figure 1.—Electrical symbols commonly used.

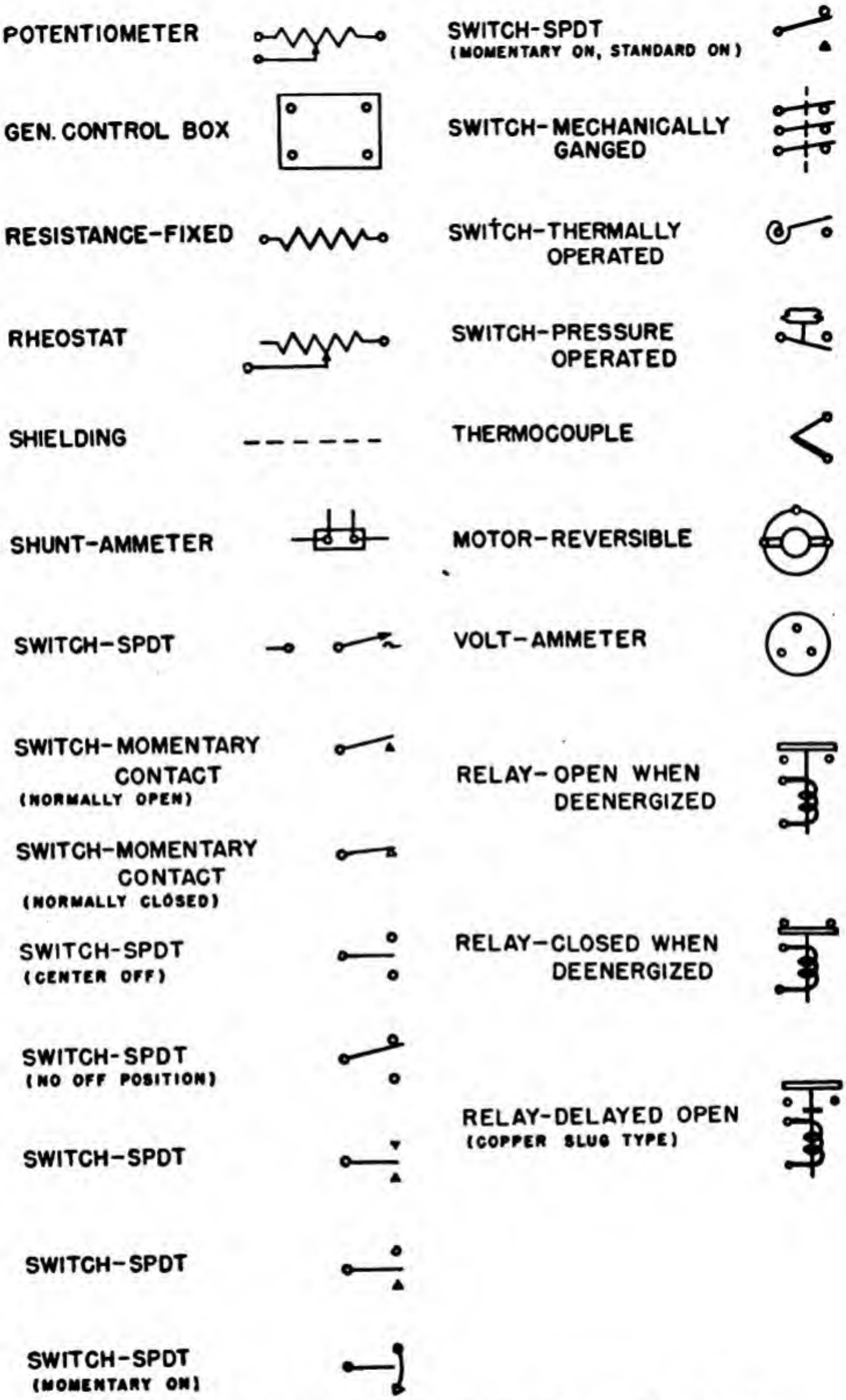


Figure 1.—Electrical symbols commonly used.—Continued

And these symbols are the key to the successful solutions to problems in aircraft electricity. They represent the language that you are going to speak. They will appear on all plans, charts, wiring diagrams, blueprints, and the like with which you will work. Learn them now, so well that you will not have to refer to the list when confronted with a problem. And how do those symbols help you? Let's see how they are used in the WIRING SYSTEMS on aircraft.

There are, in general, two types of wiring used in aircraft construction. One is the SINGLE-WIRE SYSTEM. The other, the TWO-WIRE SYSTEM. A single-wire system uses the structure of the airplane as a GROUND or RETURN circuit. A two-wire system uses an additional wire for the same purpose. The single-wire system is the one commonly used in Naval aircraft. Its application to lighting will be considered first.

With respect to LIGHTING, the single-wire system is advantageous because it involves less weight. Furthermore, it requires less material and consequently less labor for installation. These, too, are advantages because they reduce the cost of production. Figure 2 illustrates a simple system of lighting. Note the centrally located bus bar. Trace lines from switch to lights.

Magnetic fields are built up around wires which carry current. THIS is a disadvantage of the single-wire system. The magnetic fields affect the operation of certain instruments such as the magnetic compass. When another wire is added to the circuits involved and the wires are twisted around each other, the magnetic fields tend to cancel themselves.

Electrical circuits in an airplane are controlled by various types and sizes of SWITCHES. In large type aircraft, there usually is one switch called the

MASTER SWITCH. The master switch disconnects the ignition. Most airplanes have emergency circuits that always are "hot" or energized—circuits you may need in a hurry, like the fire extinguisher

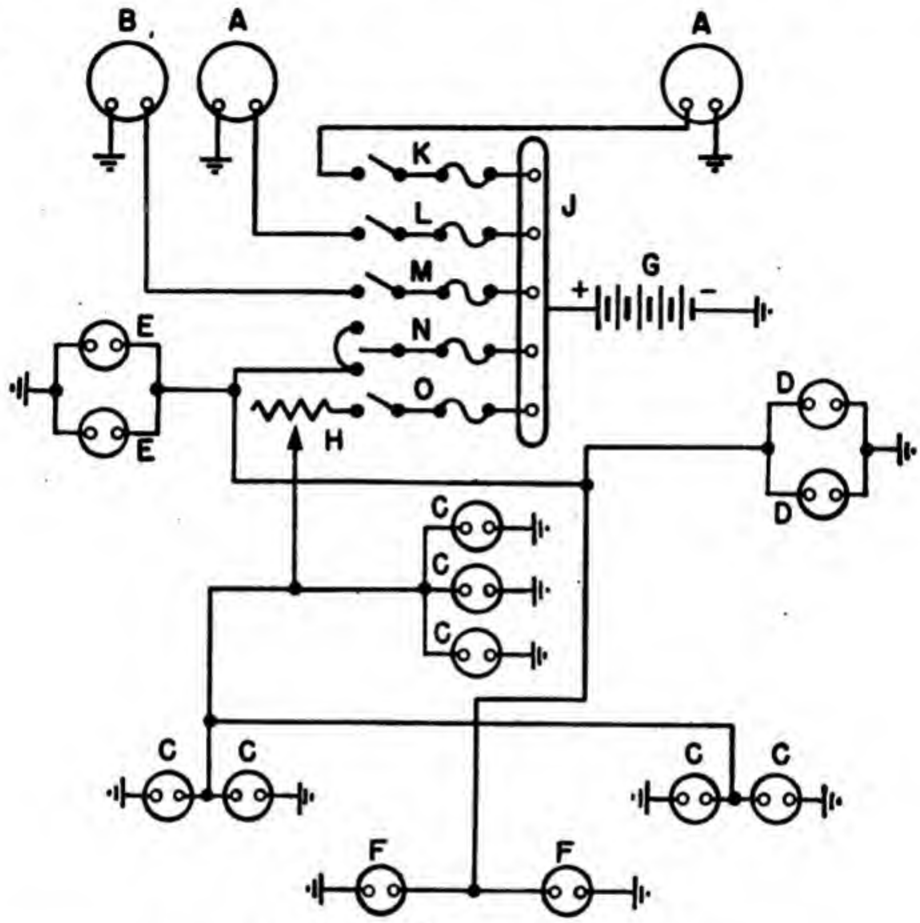


Figure 2.—Single-wire aircraft lighting system.

A. Landing lights.
B. Passing light.
C. Formation lights.
D. Navigation lights, right.
E. Navigation lights, left.
F. Navigation lights, rear.
G. Battery.
H. Rheostat, formation lights.
J. Bus bar.
K. Switch, right landing light.
L. Switch, left landing light.
M. Switch, passing light.
N. Switch, navigation lights.
O. Switch, formation lights.

circuit, the landing gear warning signal, and special communication equipment.

The master switch really constitutes the brain of the electrical system. Figure 3 gives an idea of the numerous electrical combinations found on

the master panel. Note that each generator and battery has its own master switch, which connects the units to the bus bar. Each of these connections, in turn, by means of secondary switches,

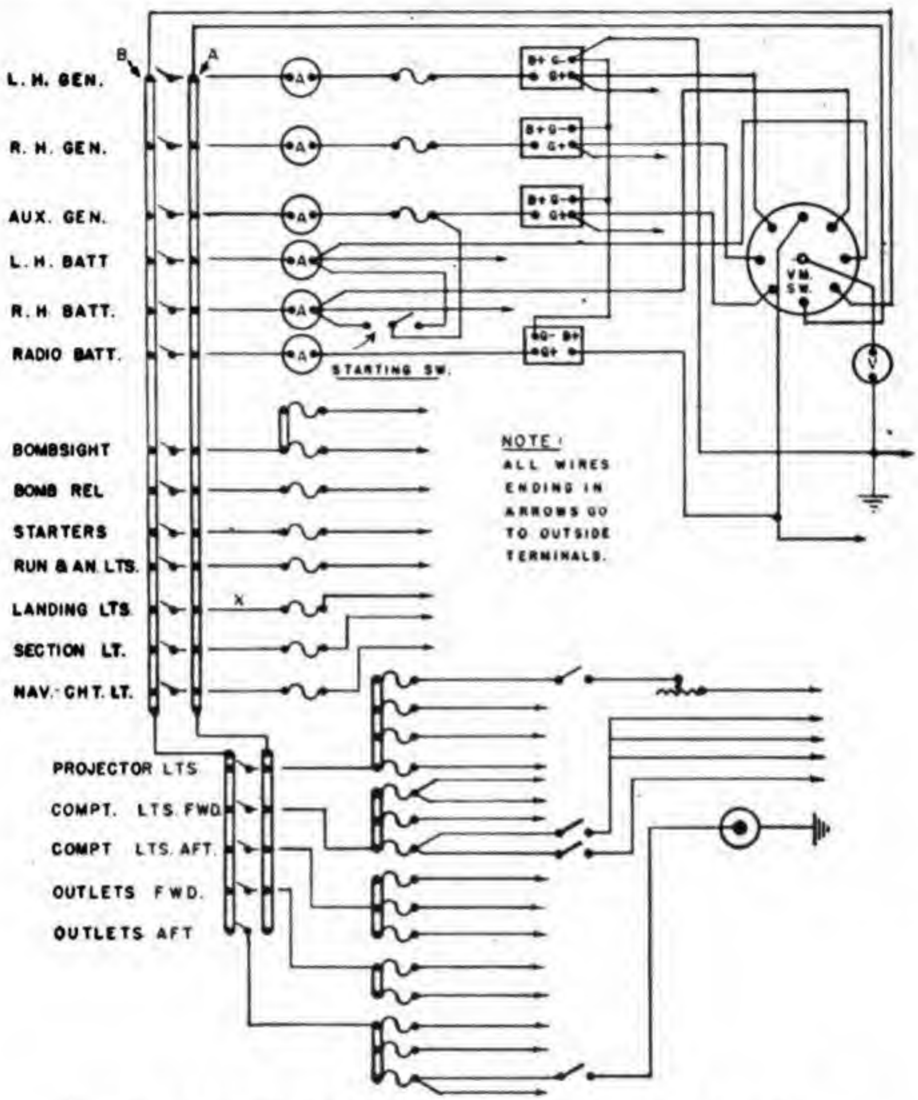


Figure 3.—Main distribution panel (large type aircraft).

makes possible the operation or nonoperation of the various lighting systems and some of the electrically controlled instruments.

These switches, for the most part, are the simple ON and OFF type. Study figure 2 in connection with figure 3. Note line *X* leads to the landing lights. Figure 2 shows wiring to the landing

lights. Combining information in the two figures makes it possible to follow the wiring from master panel to light bulb.

The TWO-WAY SELECTOR SWITCH is one type of switch used for opening and closing engine cowl flaps and wing flaps. When the switch is in the center position, it is OFF. The handle can be moved to the OPEN OR CLOSED positions. Usually incorporated in this type of switch is an automatic cut-off that prevents the motors from operating the flaps when they are fully opened or closed.

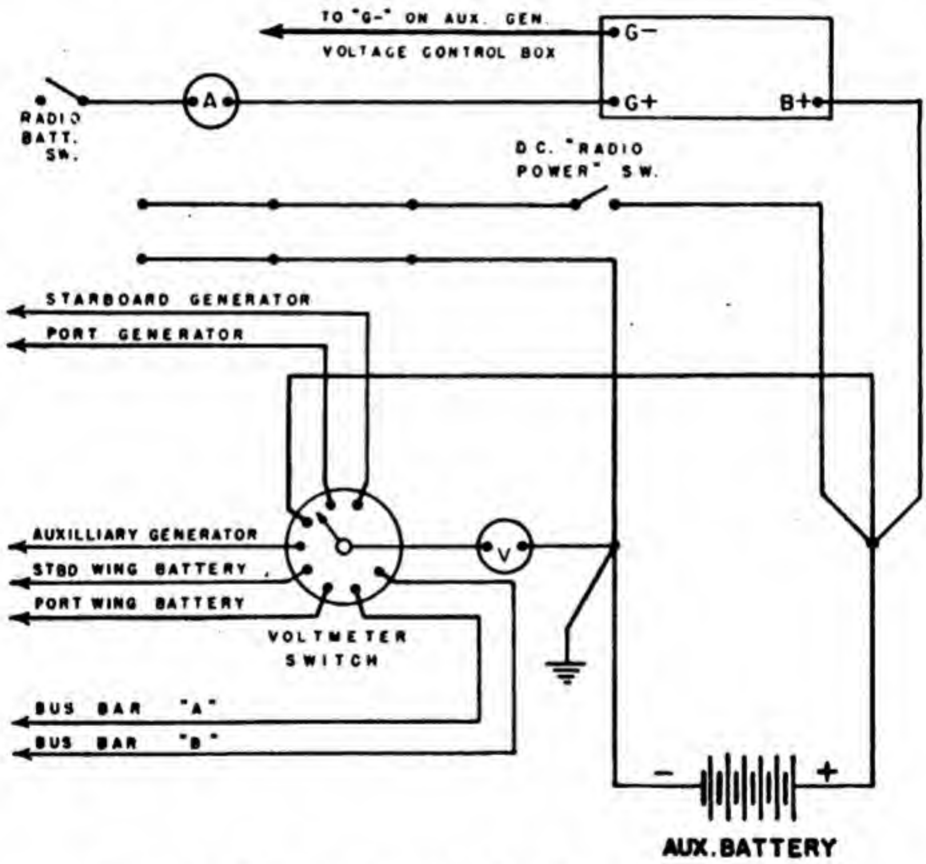
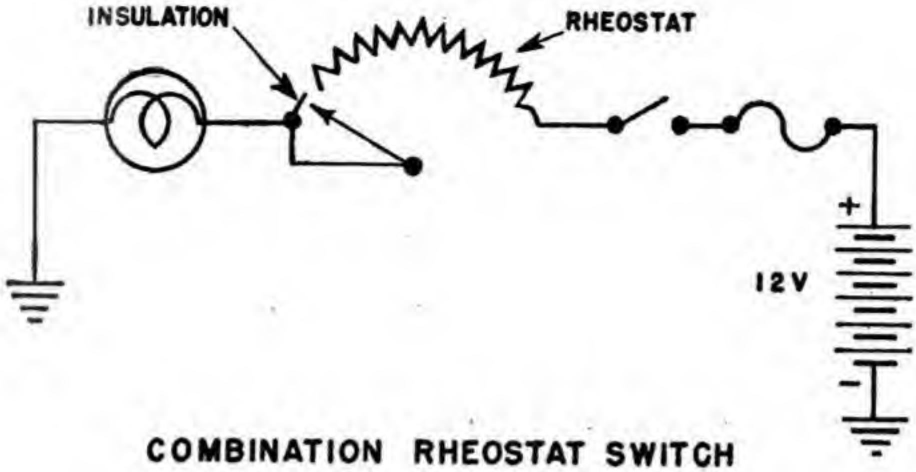


Figure 4.—Eight-position multiple voltmeter selector switch.

Some switches will stay in the position in which they are placed. Others must be held in position as they return to OFF, once pressure is removed.

The MULTIPLE SELECTOR SWITCH is constructed so that it is possible to connect any one of several



COMBINATION RHEOSTAT SWITCH

Figure 5.—Rheostat and switch combined.

circuits to a single unit or meter. For instance, the selector switch, pictured in figure 4, enables the operator to determine the voltage in any one of eight circuits. By moving the selector switch to the desired circuit connection, he keeps a close check on each separate unit. Again by studying figure 3 and 4 together, it is easy to understand the method whereby the master switch "ties in" with all circuits.

A RHEOSTAT is a variable resistor used to limit the amount of current through a circuit, or to any particular unit of that circuit. One of the most common uses of a rheostat in aircraft is to vary the intensity of lights throughout the airplane. When the maximum resistance has been reached, most rheostats turn off the current completely by opening the circuit. When the pivoting arm reaches the high resistance end of the rheostat, it slips off the contact surface as indicated in figure 5. This breaks the circuit. Sometimes it is called a RHEOSTAT SWITCH.

A SOLENOID consists of a coil and a soft iron core mounted so that the core can move inside the coil. Solenoids in a circuit are used to move a part, arm, or switch of a remote unit without a mechanical connection between the unit and the operator.

The object to be actuated is attached to the core of the solenoid. The core extends into the center of the coil far enough to be within range of the magnetic field. The core is generally held in position by a spring, by gravity, or by spring action of the part to be set in motion. Study figure 6 carefully—there are two illustrations. When the coil of the solenoid is energized by electricity, it sets up a magnetic field, and draws the core into the coil, closing the switch. When the source of energy ceases, the core returns to its original position. This position is illustrated in figure 6*A*.

The solenoid is used to close heavy duty switches in high amperage circuits such as starter motors. It is also used for gunfire and bomb release controls.

For ease of operation from a central location, most switches and meters are grouped together on a single CONTROL PANEL, as shown in figure 7. The panel may be seen readily and reached easily by the pilot, copilot, bombardier, mechanic, or radio-

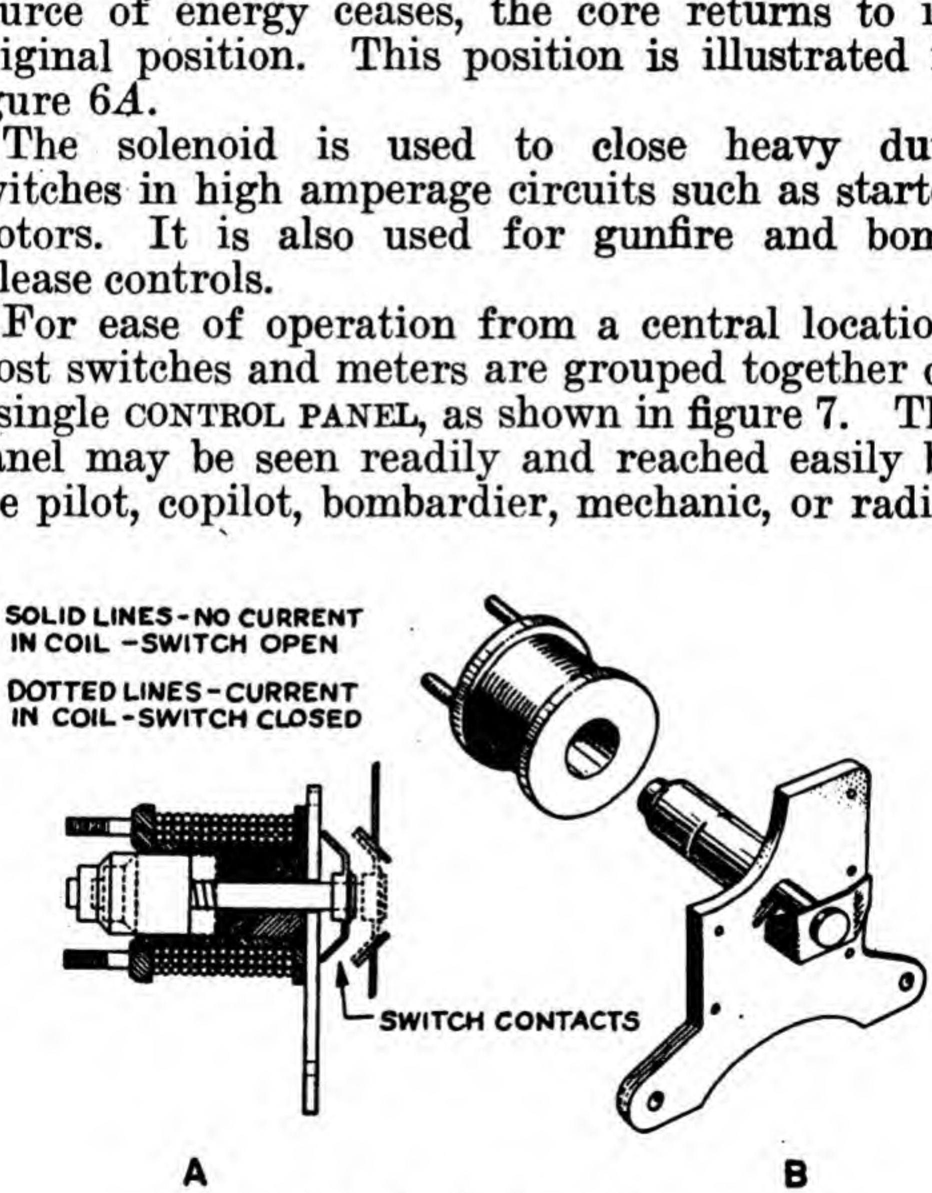


Figure 6.—Solenoid switch.

man. The panel is known as the PILOT'S SWITCH PANEL or ELECTRICAL CONTROL PANEL.

Before starting the engines or operating any of the various instruments, DETERMINE THE SEQUENCE IN WHICH THE SWITCHES ARE TO BE OPERATED.

Electrical wiring systems are divided into sections terminating in JUNCTION BOXES by means of

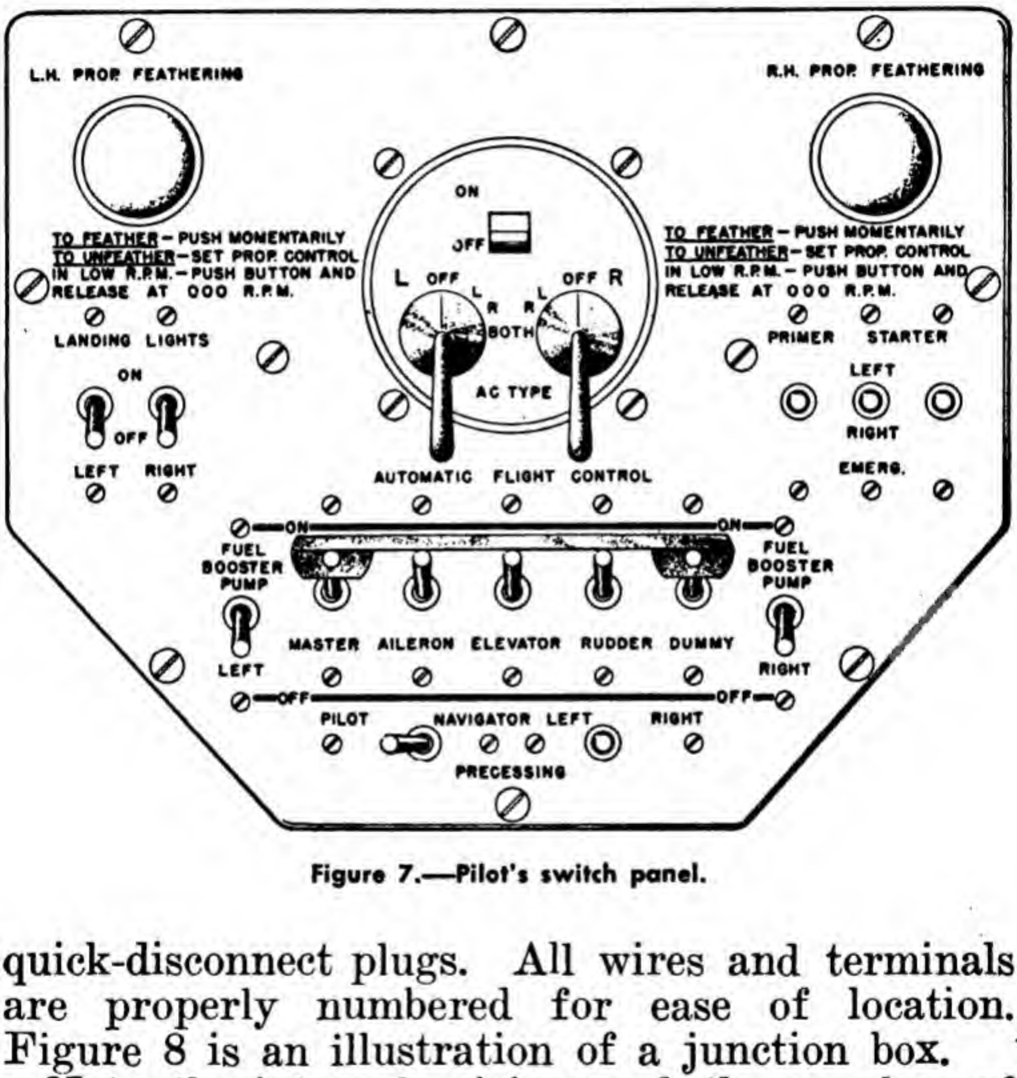


Figure 7.—Pilot's switch panel.

quick-disconnect plugs. All wires and terminals are properly numbered for ease of location. Figure 8 is an illustration of a junction box.

Note the internal wiring and the number of quick-disconnect plugs. This method of wiring permits the removal of wing panels, tail sections, motors, and defective electrical units, without cutting or unsoldering any of the wires leading to or through the section to be removed. The testing

of electrical circuits also is simplified, and removal and replacement of faulty wirings is facilitated when necessary.

In most instances, COMPLETE CABLE SECTIONS of electrical circuits, including conduits, conductors, fittings, junction boxes, terminals, and quick-disconnect plugs may be assembled in the shop. Figure 9 shows how these assemblies look when

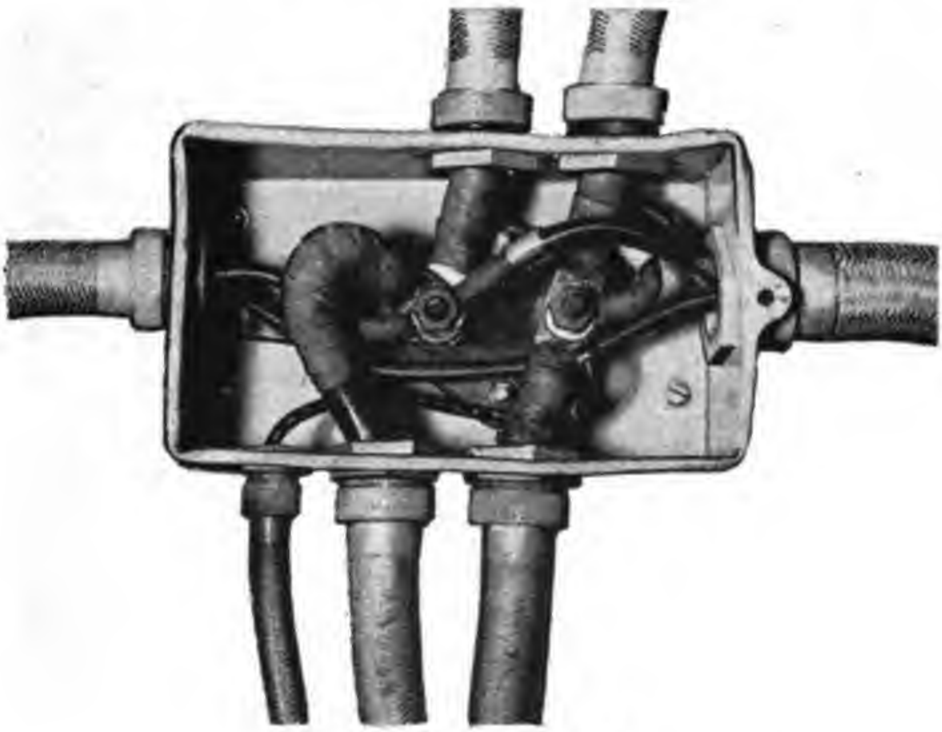


Figure 8.—Engine junction box.

delivered. Observe the junction box at the right. They may be installed directly as complete units, thus making installation simpler, and saving time and material.

All electrical circuits are provided with FUSES or CIRCUIT BREAKERS as a prevention against fire and damage to equipment. You are familiar of course with ordinary fuses—you have changed many. Those commonly used in aircraft are shown in figure 10.

The most commonly used circuit-breaker is the thermal overload relay. Figure 11*A* is a picture of a small THERMAL OVERLOAD RELAY. Figure 11*B* is a cross-section of the relay in the closed posi-

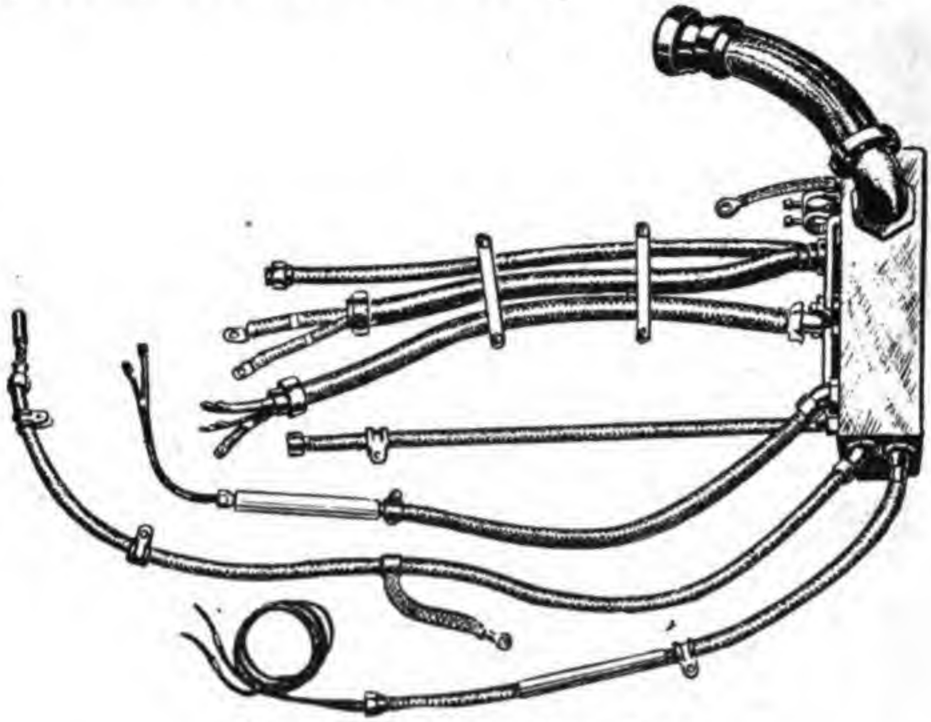


Figure 9.—Complete cable sections.

tion. Figure 11*C* shows a cross-section in the open position. Compare 11*B* and 11*C* carefully. Note the position of the contact points in the illustrations.

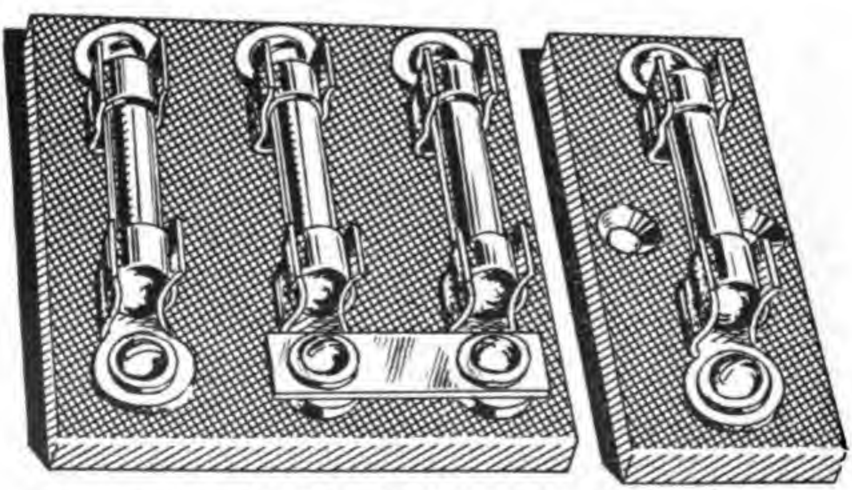


Figure 10.—Standard aircraft fuse blocks.

You will generally use the OHMMETER METHOD in testing for continuity and grounded electrical circuits. Figure 12 represents a section of the plan of an instrument light circuit for the pilot's switch panel. Compare figure 12 with figure 3 (p. 6). Can you trace the circuits? The switches, rheostats, bus bar, fuses, and lights are indicated. (How many of the symbols did you interpret without referring to the chart of symbols?) You are going to do some TROUBLE-SHOOTING with this

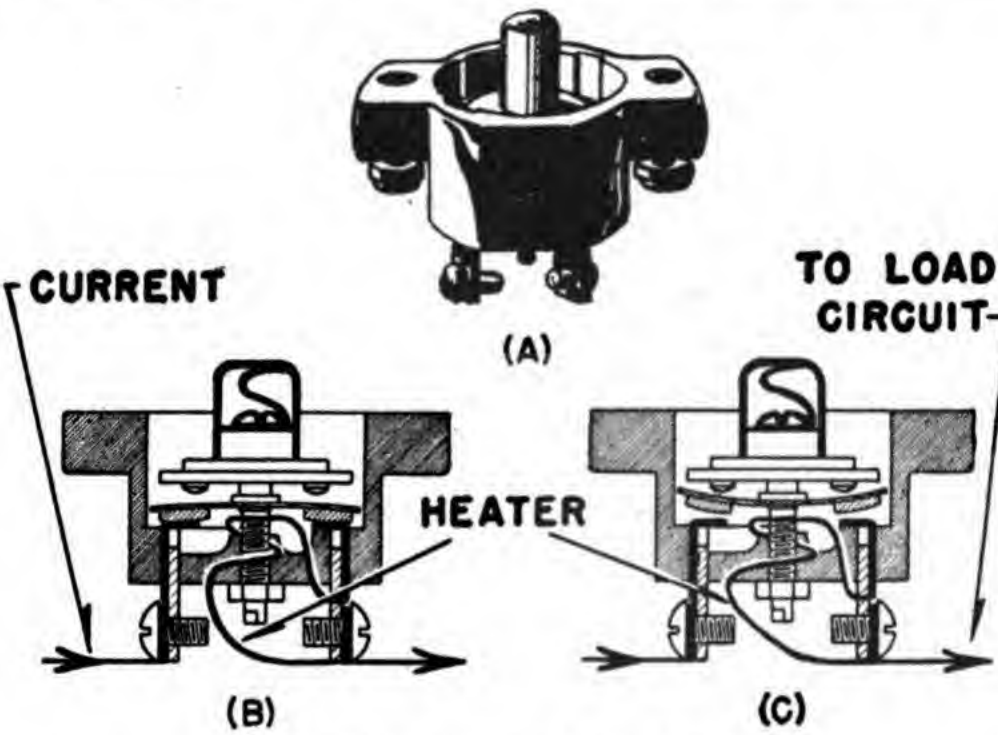


Figure 11.—Thermal overload relay.

plan as your guide. The problem you are to solve is this—the right-hand projector light is out. WHAT has caused the failure?

You have the following facts—The main distribution panel switch and the projector switch are ON, and the left-hand projector light is illuminated.

From your knowledge of electrical circuits, you can see, by consulting the diagram, that switch No. 2, the rheostat and the wire leading

to the left-hand projector light, and the fuse in series with the wire are functioning properly. Before you attempt to find the source of trouble,

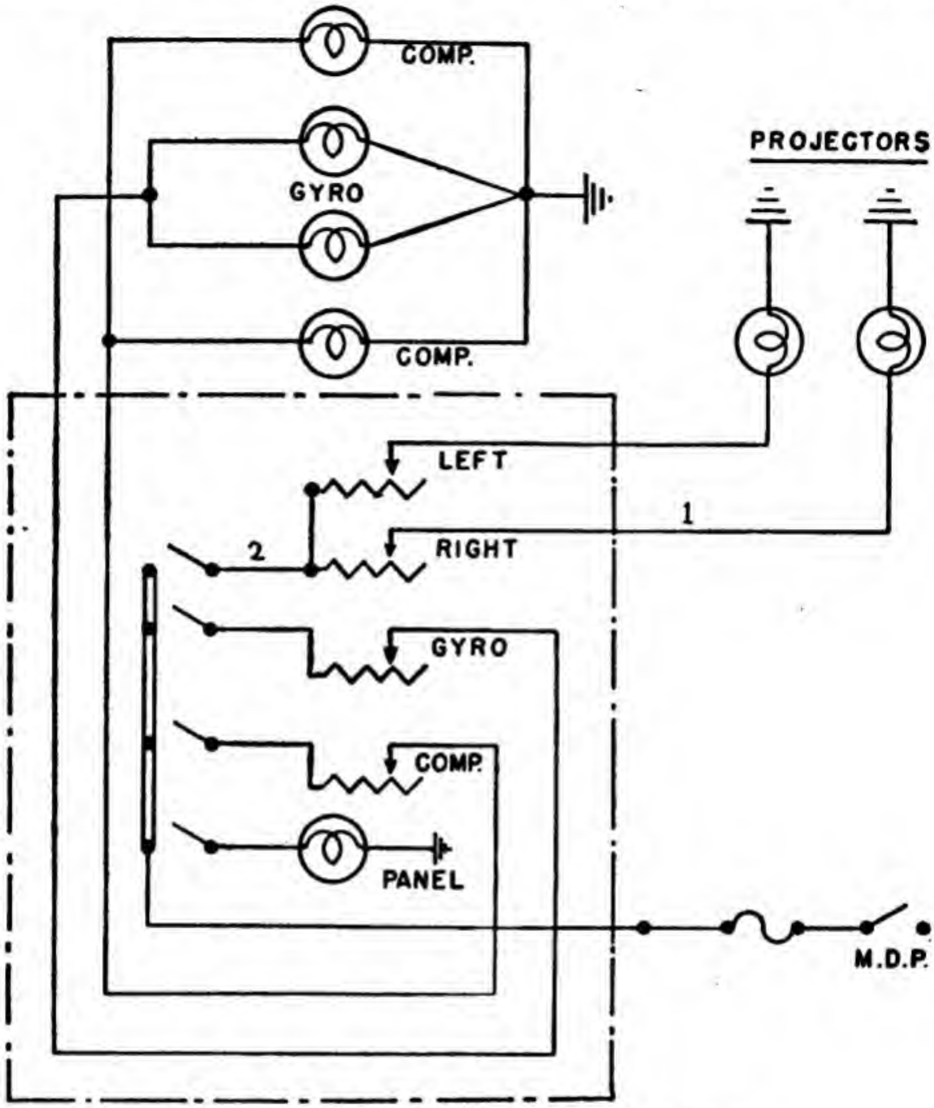


Figure 12.—Pilot's instrument light circuit.

you make the following deductions concerning the possible causes of the trouble—

The right-hand projector light is burned out.

The right-hand rheostat is open. The right-hand rheostat has too much resistance in the circuit. Wire 1 is either grounded or open.

Your knowledge of the wiring makes it possible for you to assume further that the circuit is

continuous. With these facts in mind, you CAN ANSWER THE $1 QUESTION. The trouble lies somewhere BETWEEN the right-hand rheostat, wire No. 1, and the right-hand projector lamp.

You proceed as follows—

Rotate the rheostat to its position of minimum resistance. CHANGE the light bulb, examining both bulb and socket contacts for corrosion. INSPECT all wiring connections in the circuit involved. If the light still fails to operate, you OPEN switch No. 2, removing the power from the projector light circuit. Next, you CHECK for an open or grounded wire or part in the circuit. In order to check for a short circuit to ground, you REMOVE both projector light bulbs. PLACE one test prod of your ohmmeter on the rheostat side of switch No. 2 and the other test prod on ground. You get no deflection of the meter needle on the ohmmeter scale. ANSWER! The circuit is clear.

Now to answer the next QUESTION. REMOVE the prod from the ground and PLACE it on the connection to the sliding contact arm of the rheostat. The resistance of the rheostat for the position of the sliding arm should be indicated on the ohmmeter scale. As you VARY the arm back and forth from zero to maximum resistance reading, the value on the scale should change smoothly for a properly functioning rheostat. So far, no success with your trouble-shooting, BUT you are still in the money.

SET the sliding arm of the rheostat to minimum resistance as indicated by a reading of zerò ohme on the ohmmeter. REMOVE the test prod from the rheostat connection and PLACE it on the contact of the light socket. If the ohmmeter gives a full-scale deflection, or reads a very small resistance value, you know that wire No. 1 is continuous from the rheostat to the contact in the light cir-

cuit. No trouble here! Now set one test prod on the metal barrel of the light socket, and the other on ground (any metal part of the fuselage or electrical panel). A reading of zero ohms should be obtained. Your ohmmeter, however, gives a very high resistance reading which indicates that you have located the source of trouble in the grounded side of the line.

You are up to the $64 question. You next examine carefully the ground terminal and note that it is corroded between its bottom surface and fuselage. Remove the ground terminal and clean off all corrosion from the metal surface of the fuselage and the terminal. Reinstall the ground terminal, being careful to make a tight, clean connection. Insert both projector lights in their respective sockets. Close switch No. 2. Both projector lights operate. The problem is solved. You win the money.

You must always work in a logical manner when solving problems. Not all problems will be as simple as this one. But, if you choose a definite part of the circuit as a starting point and follow carefully the wiring blueprints, you should have little difficulty. By means of experience, you will be able to deduce certain causes for defective operation almost immediately. This comes, of course, as you gain knowledge of parts and their interrelation. Always start with a plan of attack. Thought exercised at the beginning of a task will result in the saving of much time and wasted effort. Furthermore, you will accomplish more constructive work.

INVISIBLE ILLUMINATION

The pilot and crew in military aircraft must read panel instruments with a minimum of light.

The lighting MUST NOT BE VISIBLE OUTSIDE the craft. In order to accomplish this, the instrument panels are equipped with figures painted with a material sensitive to ultraviolet light. The source of illumination is not visible in itself, but when directed against the figures it causes them to glow in distinct outline form.

A FLUORESCENT LAMP ASSEMBLY with a special lens filter system, passing only ultraviolet light, is used on the instrument panel. A variable gate system on the lamp assembly permits the regulation of the amount of light emitted. This gate system is operated by an automatic starting switch. There is also an opening for the passage of visible light, when such passage is necessary.

Fluorescent lighting is usually operated from an alternating current source, provided by a motor generator or an INVERTER. Fluorescent light is not applicable to lighting certain instruments. In these cases, lighting is provided by means of small 3-volt bulbs, self-contained in the instrument cases. The voltage of the generator-battery system is used to light them by inserting voltage-dropping resistors IN SERIES with the lamps. The necessary 3 volts may also be obtained from an a-c winding on the inverter.

Figure 13 is an INVERTER which changes the direct current of the generator-battery system into 110 volts a. c. at a frequency of 400 cycles per second.

When the switch (*SW*) is closed, direct current passes to the center tap of the transformer and divides. Part of the current passes from the center tap to point X by way of the coil K_1 and the resistor R_1. This energizes K_1, causing it to draw the armature against the upper point. Closing the points short circuits the coil and R_1

in parallel with it, thereby increasing the current through the upper half of the primary winding.

The short circuit also releases the armature V_1 which, because of spring tension and inertia,

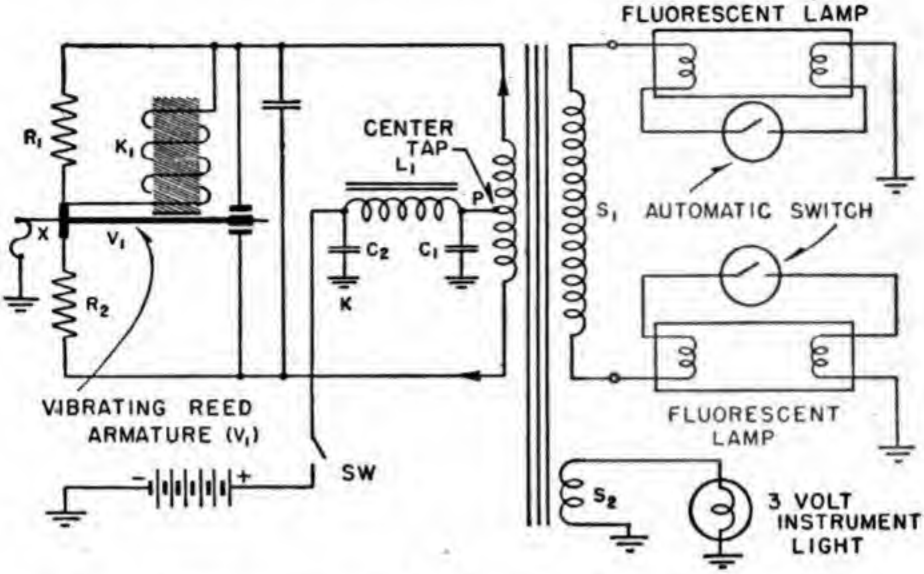


Figure 13.—Inverter system for fluorescent and instrument lights.

moves against the lower contact. This action, in turn, short circuits resistor R_2, causing the major portion of the primary current to shift and flow through the lower portion of the primary winding. Because the short has been removed, coil K_1 again attracts the armature. The armature vibrates from one pole to the other. This cycle of events is repeated at the rate of 400 TIMES PER SECOND.

The action just described produces a pulsating current in alternate sections of the primary winding. The expanding and collapsing magnetic field induces a high a-c voltage in the secondary winding. The voltage has a frequency corresponding to the vibration rate of the armature V_1 and is used to energize the fluorescent lamps. Another secondary winding S_2 is used for direct lighting of the full, or open throttle.

The arcing that occurs at the points of the vibrator produces a RADIO FREQUENCY WAVE which causes interference (noise) in the radio receivers. This noise is eliminated by using a filter circuit comprising inductance L_1 and capacitators C_1 and C_2.

When the aircraft is equipped with a central 110-volt, 400 cycle, a-c power supply, an AUXILIARY BOX may be used to operate the fluorescent lamps.

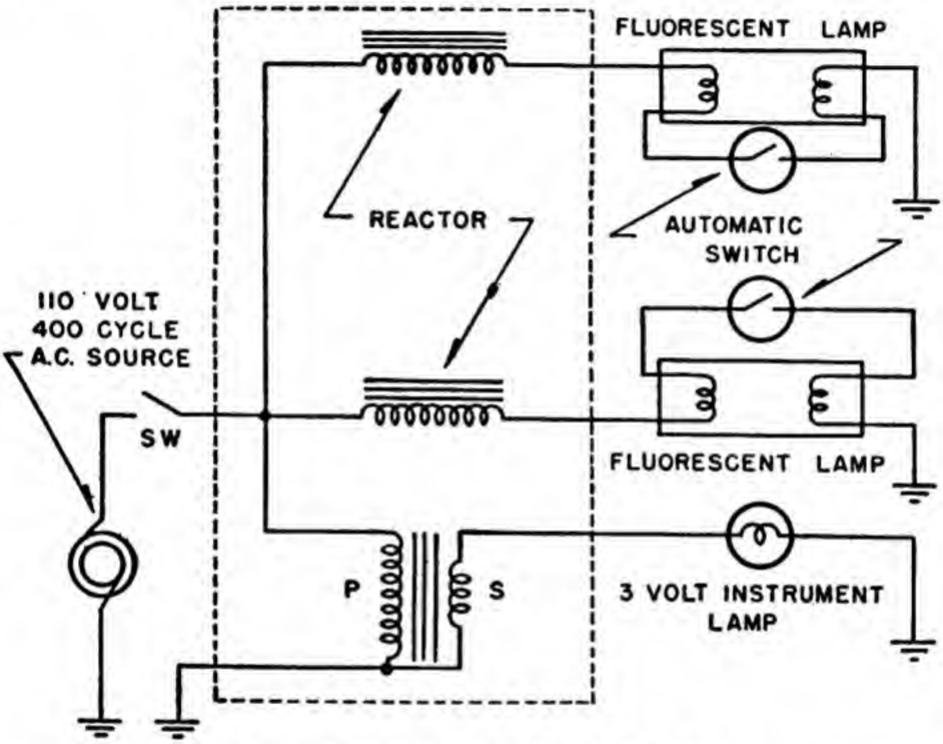


Figure 14.—Power supply auxiliary box.

The box, pictured in figure 14, includes a REACTOR for each fluorescent lamp, and a STEP-DOWN TRANSFORMER for the 3-volt instrument lamps.

INDICATOR LIGHTS

Since retractable landing gear has been added to Naval aircraft, there have been instances in which pilots have landed with their landing gear

in the UP position. This means that they have forgotten to release the landing gear and, as a result, have swooped in and taken a good old fashioned "belly-whopper." Then, too, there have been cases of pilots having landed with only one side of the landing gear mechanism locked. You can picture this type of lop-sided landing. When only one wheel is down, the crash is a bad one and means that the airplane must undergo a major overhaul. If both wheels are unlocked, the crash is terrific and often results in injury or death to occupants of the airplane.

In order to prevent accidents at landing or take-off, various warning systems have been developed.

In figure 15 is illustrated a schematic diagram of one simple representative system—a LANDING GEAR AND WING INDICATOR SYSTEM. A pilot about to land with gear retracted (UP) is warned by the sound of a HOWLER. Microswitches, mounted in each side of the landing gear, control the howler. When either wheel is in a retracted position, the microswitch for that side is in the closed position, thus operating the howler. Because the switches are connected IN PARALLEL, the howler circuit is broken ONLY when BOTH WHEELS are fully extended and locked.

Two other circuits are IN SERIES with the howler circuit—the CHECK-OFF INSTRUMENT and the THROTTLE SWITCH. The check-off instruments—a device for listing the operations required for a take-off or landing—is provided with a single-pole double-throw switch. The switch is closed when placed in the LAND position. The throttle switch, coupled mechanically to the throttle rod, closes when the engine is throttled to a speed within landing range. This is approximately one-eighth of the full, or open throttle.

In normal flight, the pilot about to make a landing sets the check-off instrument in the LAND position. He then throws the gear control lever to the DOWN position. If the landing gear DOES NOT operate properly, the landing gear microswitches

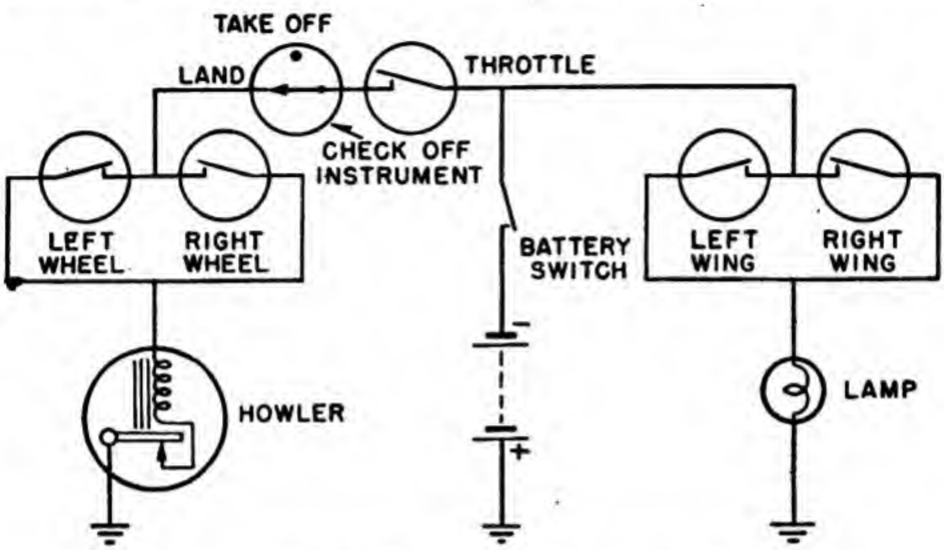


Figure 15.—Landing gear and wing indicator system.

remain closed. At this point, the circuit is broken at one place only—the throttle switch. As the pilot comes in for the landing, he reduces the throttle setting, thus closing the break. The howler immediately operates and warns him that the gear is not down.

In addition to the warning system, figure 15 also shows the lighting system used to indicate the locked position of the wings. Microswitches, controlling these lights, are mechanically connected to the lock pins on each wing. NORMALLY the switches in the circuit are closed. They open only when the wings are locked in place. If the wings are in the unlocked position, current flows to a RED INDICATOR LIGHT on the instrument panel. The light is placed so that it shines directly into the pilot's eyes—it is extinguished only when the wings are locked in place.

The warning system, however, pertains only to the extended position of the landing gear. It gives no information to the pilot concerning landing gear fully retracted. Because an airplane's performance, particularly its speed, is affected by the position of the gear, it is important that the gear be retracted fully. Most of the smaller Naval aircraft are equipped with mechanical indicators for noting landing gear position. In a few larger types, electrical position indicators of the d-c Selsyn type are used.

Figure 16 is a simplified diagram of the d-c SELSYN REMOTE POSITION INDICATOR. The transmitter consists of a rheostat with two rotating contactors fastened to a shaft which, in turn, is mechanically connected to the landing gear. The degree of rotation of the shaft is determined by the distance the landing gear has moved from its normal position.

The indicator consists of a winding on a laminated steel Gramme ring. The winding has three equally spaced taps which connect to equally spaced taps on the transmitter rheostat. Hence voltage across sections of the rheostat is applied to coils on the Gramme ring. The current-flow in the ring sets up a magnetic field diametrically across the ring. The position (diameter) on the ring at which this field emerges depends upon the position of the transmitter shaft.

A permanent magnetic rotor is placed in the center of the Gramme ring. The rotor alines itself with the magnetic field across the ring. The field shifts because of changes in voltage distribution on the transmitter rheostat. As the shift occurs, the rotor changes position. A pointer attached to the rotor changes with it and indicates on the dial the exact position of the landing gear.

When the power is off, the rotor returns to the OFF position. Because there is no electromagnetic field present at the time, a small permanent magnet is added to the unit in order to bring the rotor to a definite position of rest.

The d–c Selsyn indicator, as described, is used not only as a landing gear position indicator, but

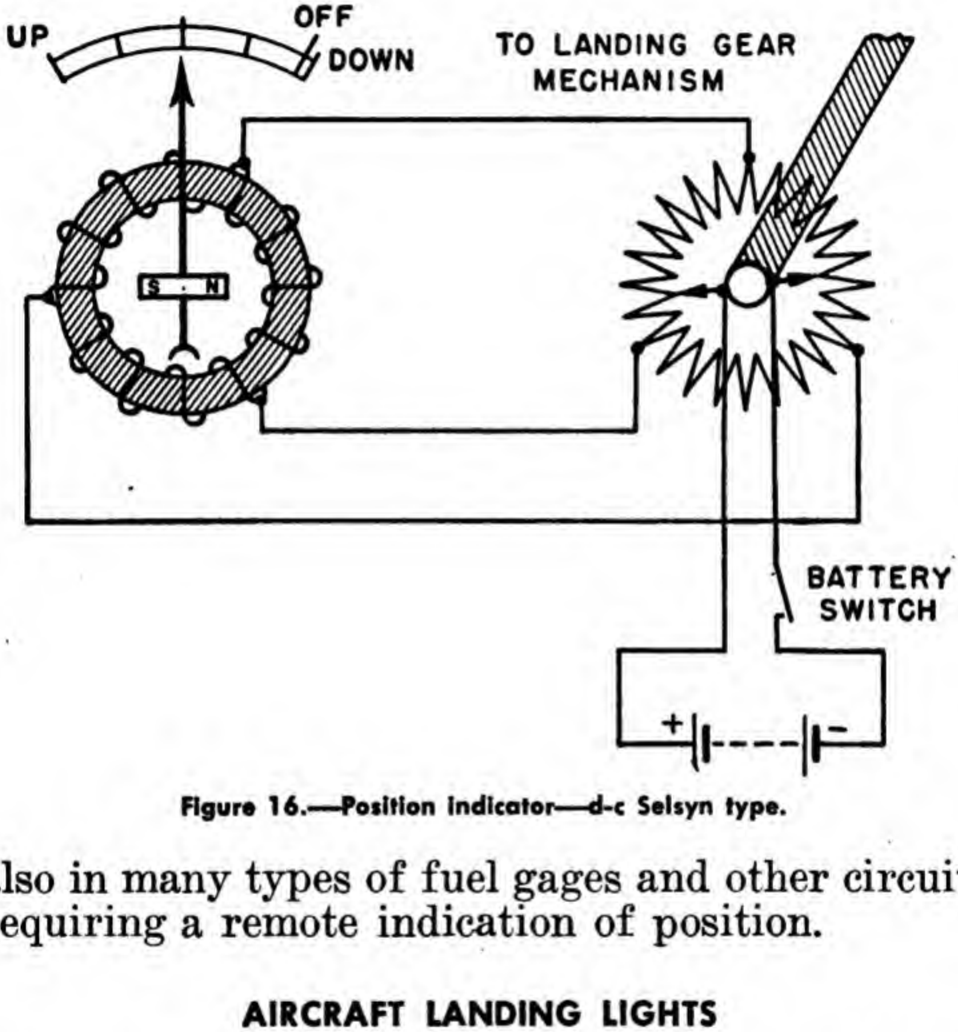


Figure 16.—Position indicator—d-c Selsyn type.

also in many types of fuel gages and other circuits requiring a remote indication of position.

AIRCRAFT LANDING LIGHTS

Landing lights are low-powered searchlights. Either FIXED or RETRACTABLE types may be used. The fixed type is mounted at the leading edge of the left wing. The retractable type is mounted in the lower panel of the left wing. In larger aircraft, a landing light is installed in each wing.

The fixed landing light consists of a SEALED BEAM UNIT, a SOCKET, and a PROTECTIVE COVER. In a sealed beam unit, both the filament and the reflecting surface are in a vacuum. Thus, the reflecting surfaces are not subject to tarnish and loss of reflecting power. Consequently, both reflector and lamp must be replaced when a lamp burns out. Usually the lamp is secured in the wing by means of a holding band tightened by a screw. The complete unit is mounted inside the wings about 6 inches from the leading edge. A protective shield of plastic glass, shaped to conform to the contour of the wing, is placed in front of the lens.

Figure 17 shows the mechanisms of a standard RETRACTABLE LANDING LIGHT of the type used in most Naval aircraft. The light is mounted so that it offers little wind resistance when retracted. Furthermore, it may be adjusted to any desired position when in use.

The landing light is composed of four parts—the LAMP ASSEMBLY (consisting of a reflector in its case), a LAMP BULB, LAMP SOCKET, and LENS. The lamp assembly is enclosed in a protective device called the housing case. A retracting mechanism contained in a pot-metal case, is attached to the housing case. An electric motor and electrically operated brake assembly are attached to the retracting mechanism.

The shaft of the motor, extending into the pot-metal, is fitted with a small gear meshed to the teeth of a slotted retracting arm. The retracting arm is constructed of cast aluminum alloy. It is hollow in order to accommodate the wiring of the lamp. One end of the arm is riveted to the lamp assembly. The other end extends into the case containing the retracting mechanism. The re-

tracting arm is fitted with teeth which mesh with the drive motor gear.

A schematic diagram of a retractable landing light is shown in figure 18. At the extreme end of the retracting arm, a sliding contact *A* is mounted for supplying current to the lamp bulb. The sliding contact wipes the metallic arc *B*. *A* and *B* make electrical contact after the light has

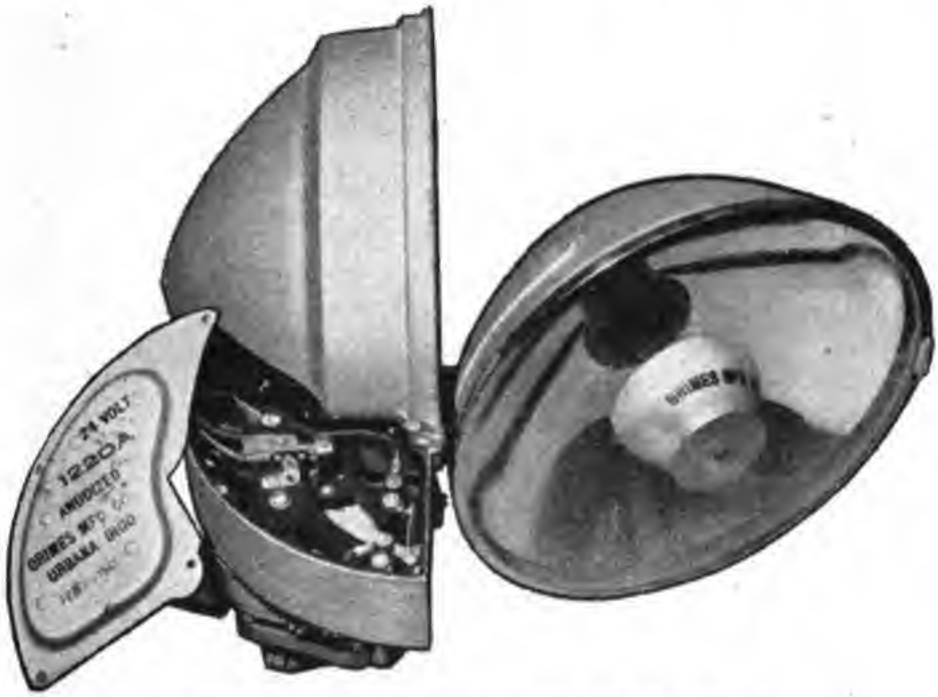


Figure 17.—Retractable aircraft landing light.

been extended about 10°. Two other contact points, *C* and *D*, limit the distance the lamp assembly may travel. The points at *C* are opened by the lamp as it reaches its FULLY RETRACTED position. The points at *D* are opened by the lamp as it reaches its FULLY EXTENDED position. Opening of the contacts is effected by an insulated flange attached to the upper end of the retracting arm which bunks against the contact arm.

The motor and brake assembly consist of a small d-c SERIES motor, equipped with a split field

winding. One side of the armature connects into the center tap of the winding. By sending current through different halves of the winding, it is possible to reverse the rotational direction of the armature. Control switch *S* determines the direction of rotation, that is, which half of the field winding is to be energized.

The motor also is equipped with an electrically operated mechanical brake. A solenoid (electromagnet) releases the brake when current flows through the motor. If the current is interrupted,

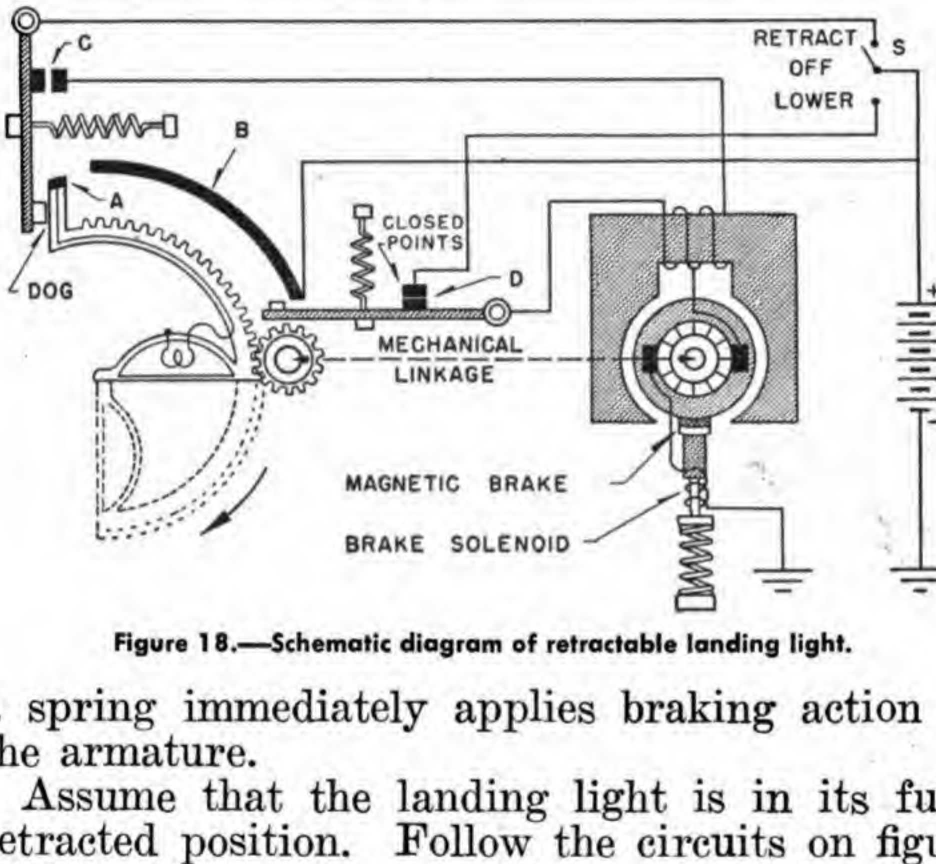


Figure 18.—Schematic diagram of retractable landing light.

a spring immediately applies braking action of the armature.

Assume that the landing light is in its fully retracted position. Follow the circuits on figure 18 from this position to a fully extended position and return. Here is what happens—

> Throw control switch *S* to the LOWER position. Battery current flows through the limiter contacts at *D*, motor field, armature, and brake solenoid. The motor rotates. The landing light starts downward. After mov-

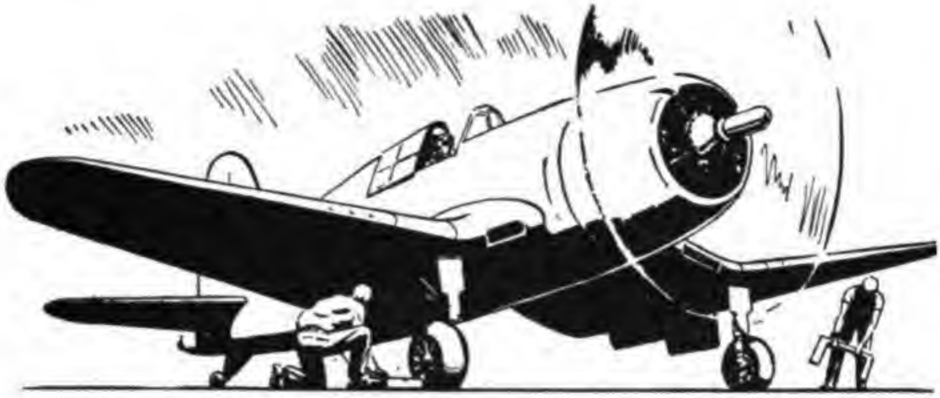
ing through 10° of travel, sliding contact *A* reaches contact arc *B*. Current flows to the lamp filament and lights the lamp. The lamp then continues to its fully extended position.

To retract the light the operations are reversed. Throw control switch *S* to RETRACT position. Battery current flows through the limiter contacts at *C*, the right side of the motor field, the armature, and the solenoid. The motor rotates. After 90° of travel, contact *A* slides away from arc *B* and breaks the lamp circuit. The lamp is extinguished. The light continues to the fully retracted position.

Having reached this point, the contact points at *C* open. This opens the motor circuit and the current cannot flow in any part of the device. The brake immediately stops the motor.

This type of landing light requires a minimum of effort on the part of the pilot. He throws the switch to the LOWER position when approaching for a landing and the lamp operates automatically. After landing, he throws the switch to RETRACT and the light returns, extinguished, to its normal position in the wing. The pilot may stop the landing light at any position within its range of travel by setting the control switch to OFF as the lamp reaches the desired position. With the switch in this position, the lamp circuit is the only complete circuit.

The retractable landing light draws a heavy current. Ordinarily, the current for the light and the motor are supplied by the generator. If the engine is not in operation, the current may be supplied by the battery. The battery, however, would be discharged within a short period of time and the light could not be retracted.



CHAPTER 2

STARTERS

TYPES

When aviation was in its infancy, there was a popular song entitled "Come, Josephine, In My Flying Machine." And Josephine rode in an airplane that was HAND-CRANKED because in the early days of aviation, the engines were small and could be started manually by turning the propeller. With the development of larger engines, improved methods of starting became necessary. The primary requisite of a starter is that it MUST crank the engine fast enough and long enough to insure a start. Secondary requisites are, of course, dependability, minimum weight, and ease of installation and maintenance.

Four general types of starters, which have been proved to be satisfactory, are INERTIA (including HAND and HAND-ELECTRIC), DIRECT CRANKING ELECTRIC, COMBINATION ELECTRIC INERTIA—DIRECT CRANKING, and CARTRIDGE or COMBUSTION STARTERS. The type of starter installed on an airplane is usually determined by the type of airplane as indicated in the following tabulation.

Airplane type	Starter type
VF	Cartridge.
VN, VSN	Hand inertia or hand-electric inertia.
VOS, VSO	Cartridge.
VPB	Hand-electric inertia or combination electric inertia—direct cranking starters.
VSB	Hand-electric inertia.
VTB	Hand-electric inertia.

There are, however, deviations in numerous instances when specific problems arise.

INERTIA STARTERS

With INERTIA STARTERS, the energy stored in a rapidly rotating flywheel is used to start the engine. This energy is transferred from the flywheel to the engine by means of speed-reduction gears and a starter jaw which engages a similar jaw on the engine. An overload protective device, consisting of multiple disk clutch under spring pressure, prevents any damage to the starter in the event of engine kick-back or overload.

There are two methods for putting the energy in the flywheel. These are—by HAND and by ELECTRIC MOTOR. For hand operation, as in figure 19, a crank is connected to the starter by means of either a rigid shaft or a flexible shaft. The gear relationship between the crank and the flywheel is such that one turn of the hand crank gives a number of turns to the flywheel. When a rigid extension shaft is used, the gearing is always in the starter. When a flexible shaft is used, a gear box is used between the crank and the flexible shaft so that the shaft rotates approximately 30 times as fast as the crank. Another gear step-up of ap-

proximately 1 to 3 is also included at the starter end of the flexible shaft. The flexible shaft is of much value when there is interference between the various accessories on the engine. Ordinarily

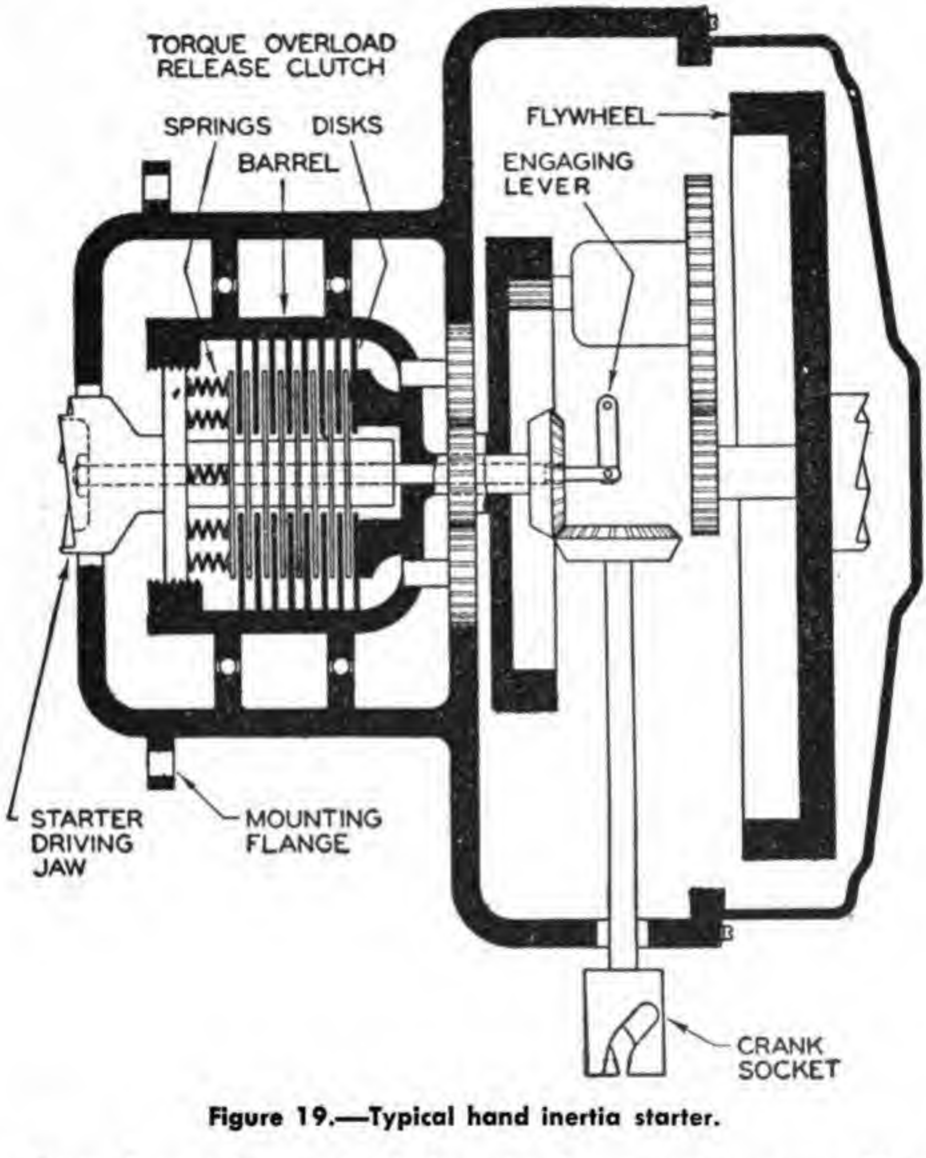


Figure 19.—Typical hand inertia starter.

the hand-crank outlet is at the engine nacelle in such a position that the cranking operation can be performed from the ground or deck, except in the case of seaplanes and flying boats where the cranking is accomplished from the wing. A manual meshing control is provided for engaging the starter to the engine.

The hand provisions on hand-electric inertia starters are the same as for the hand inertia starter. An electric motor may be attached to the hand inertia starter, thus making it possible for the flywheel to be accelerated by either a crank or the electric motor. An Eclipse series #40, found on patrol bombers, is an example of the combination hand and electric inertia type. A diagram of this type starter is shown in figure 20. A schematic is shown in figure 21.

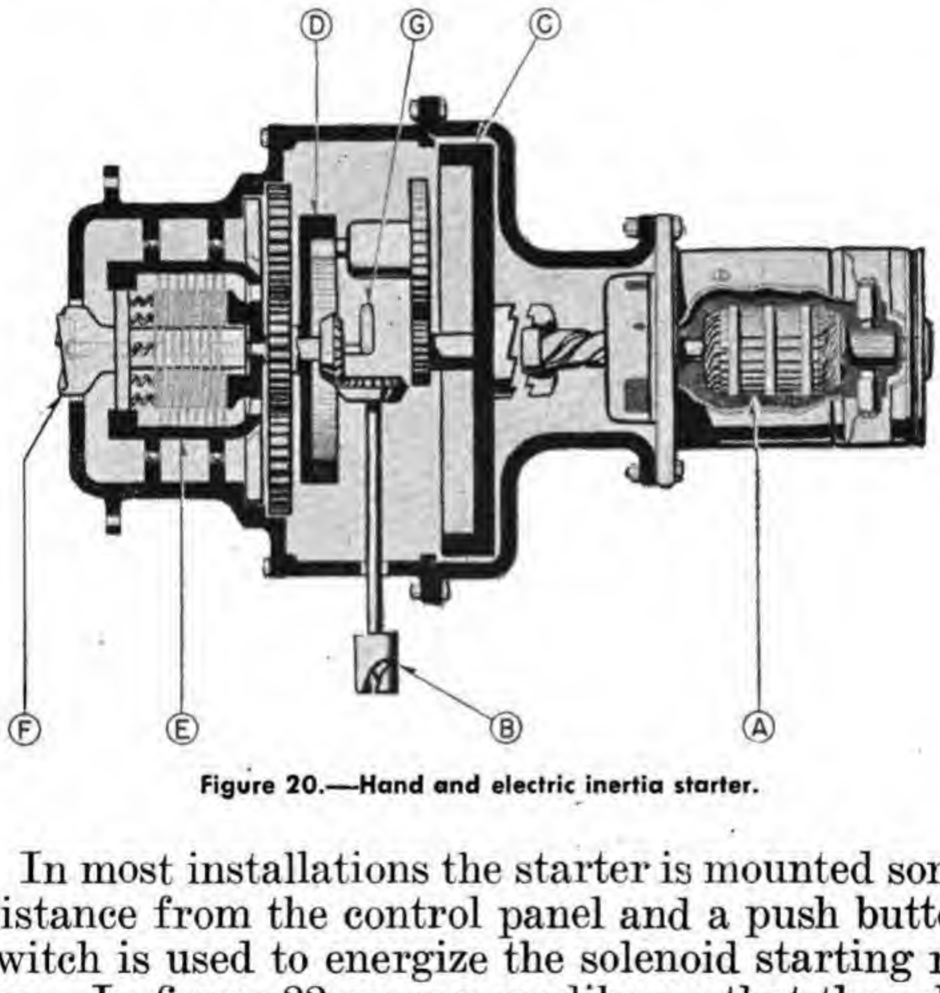


Figure 20.—Hand and electric inertia starter.

In most installations the starter is mounted some distance from the control panel and a push button switch is used to energize the solenoid starting relay. In figure 22 we can readily see that the solenoid is energized by a small amount of current controlled by the push button switch. This arrangement makes it possible for the heavy current carrying wires to be relatively short in length. Included

with this type of starter is a meshing solenoid which electrically controls the engagement of the inertia starter when desired. The meshing sol-

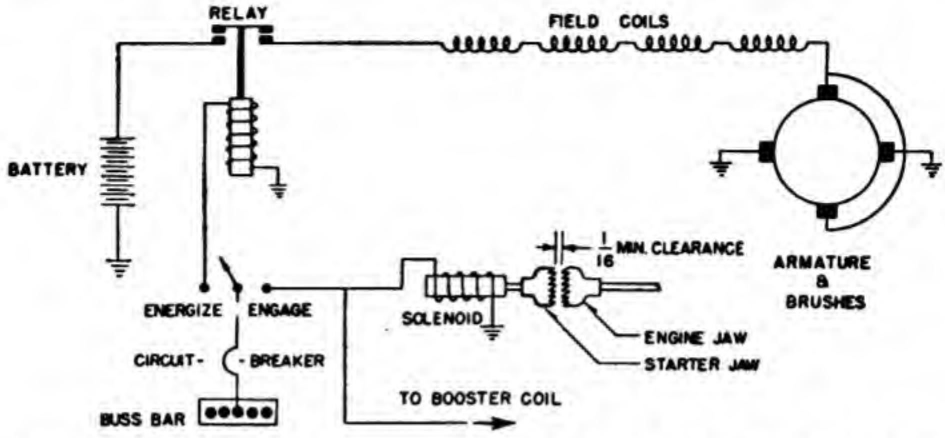


Figure 21.—Schematic diagram, Eclipse series 40 hand and electric inertia starter.

enoid plunger is connected to the starter jaw engaging lever.

Inertia starters crank an engine to a peak speed of 60 to 100 rpm but for only a very small number of turns, usually from 3 to 6. If the start is not

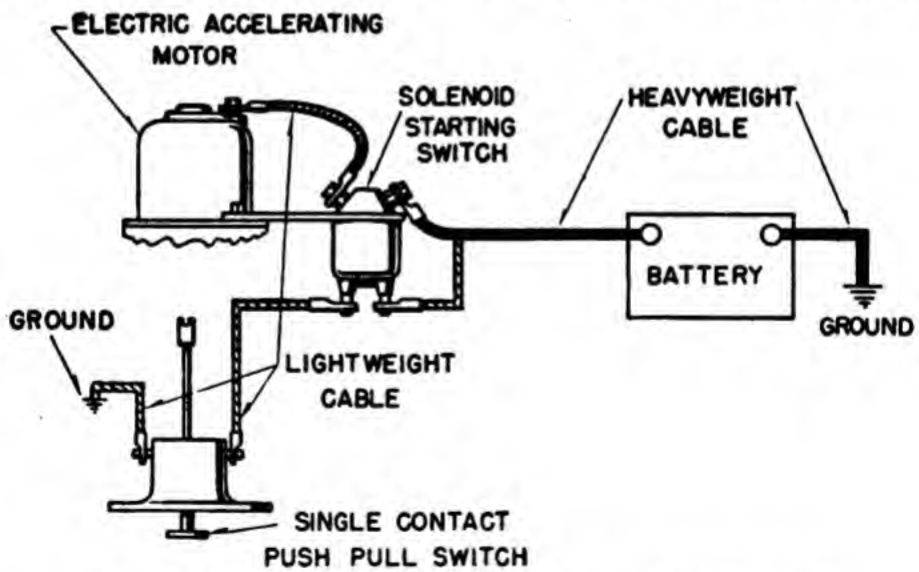


Figure 22.—Wiring diagram for an electric inertia starter.

made, the flywheel has to be accelerated to rated speed again before cranking the engine.

The operation is simple. Turning the ignition switch "on" places battery voltage on the cockpit control switch. Placing the control switch on "energize" position closes the solenoid switch and the inertia starter which increases in speed until sufficient speed has been attained. The cockpit control switch is now placed in the "engage" position, actuating the meshing solenoid and energizing the booster coil supplying the high voltage for ignition. The function of the booster coil will be discussed later.

DIRECT-CRANKING STARTERS

Similar to the automobile starter is the DIRECT-CRANKING HAND AND ELECTRIC STARTER. The Eclipse E–160 is of this type and is not very widely used due to the heavy current necessary to develop a sufficient torque. Basically, it differs from the inertia type inasmuch as the engine is cranked directly by the starter. There is no preliminary energy stored in a flywheel as in the inertia type, and hence, there is no waiting to bring the flywheel up to a satisfactory speed. That is, it cranks the engine directly by means of an electric motor as long as the starter switch is held "ON." The cranking speeds obtained from direct cranking starters are lower than those obtained from inertia starters, but the cranking time can be continued until a start is made. Normally, a direct cranking starter should not be used for more than 30 seconds. Then the starter should be permitted to cool a few minutes before making another starting attempt.

COMBINATION ELECTRIC INERTIA-DIRECT STARTERS

A COMBINATION ELECTRIC INERTIA-DIRECT CRANKING STARTER is, as the name indicates, a combina-

tion of inertia and direct-cranking starters, as illustrated in figure 23. The construction is such that the flywheel is accelerated by means of an electric motor, then the motor continues to crank the flywheel and consequently, the engine, as soon as the starter is engaged. Combination starters usually have hand-cranking provisions to enable them to be used as hand-inertia starters in the event of electrical power failure.

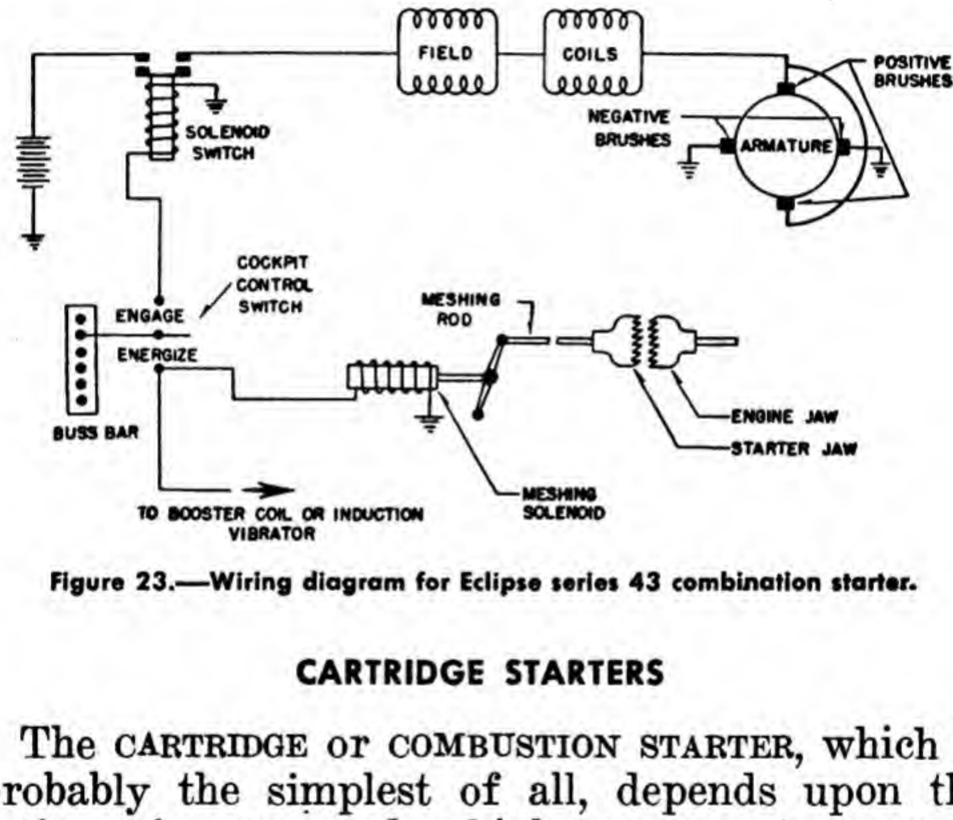


Figure 23.—Wiring diagram for Eclipse series 43 combination starter.

CARTRIDGE STARTERS

The CARTRIDGE OR COMBUSTION STARTER, which is probably the simplest of all, depends upon the action of a gas under high pressure to move a piston. The movement of the piston is converted into a rotary motion by means of a series of helically splined shafts. Such a starter is shown in figure 24.

There are two manufactures of this type of starter. The following table shows typical installations you may encounter.

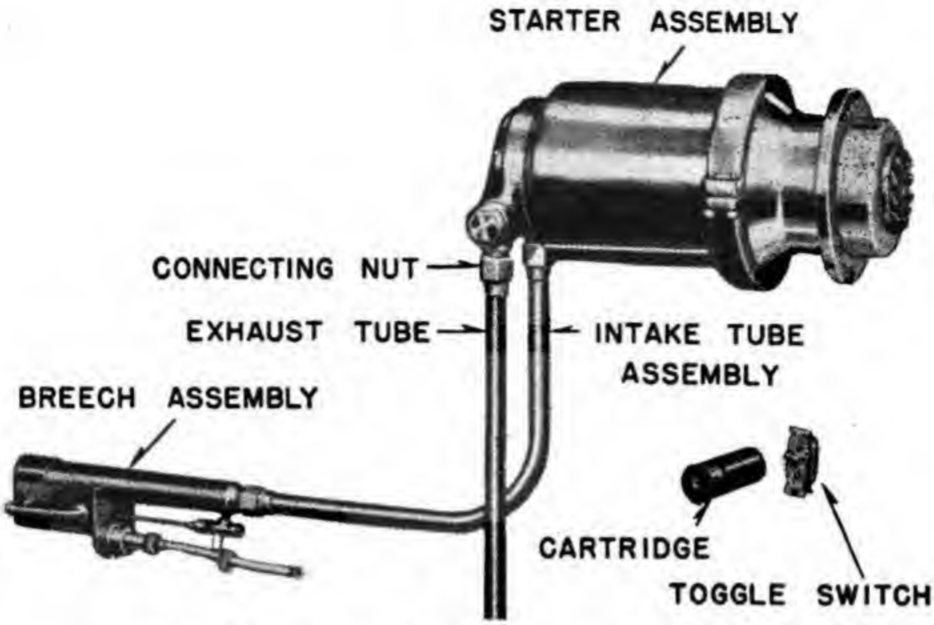


Figure 24.—Pictorial view of cartridge type starter.

Size	Eclipse	Breeze—"Coffman"
I	OS2U	SO3C
II	F2A	F4F–FM1
III	F6F–F4U	F6F

The general principles and operation of both types are the same. A cartridge resembling an ordinary shotgun shell is inserted in the breech barrel. Closing the toggle switch, electrically ignites the cartridge. The pressure developed propels the ignited fuel through the intake tube to the FUEL COMBUSTION CHAMBER where its combustion is completed. This combustion energy causes the PISTON to move forward which, by means of a series of helically splined shafts, converts the movement into a rotary motion necessary to engage the starter jaw with the engine dog. On completion of the stroke of the piston the combustion gases escape through the exhaust valve. The return of the piston to its initial position is effected by the SPIRAL COIL SPRING while the exhaust valve automatically closes.

The only electrical action occurs during the actual firing of the cartridge. The resistance of the circuit (shown in figure 25), exclusive of the cartridge, should be approximately 1 ohm. The current necessary to discharge an electrically match-fired cartridge is 1 ampere. In an emergency, a unit cell of a flashlight battery may be used as a source of energy.

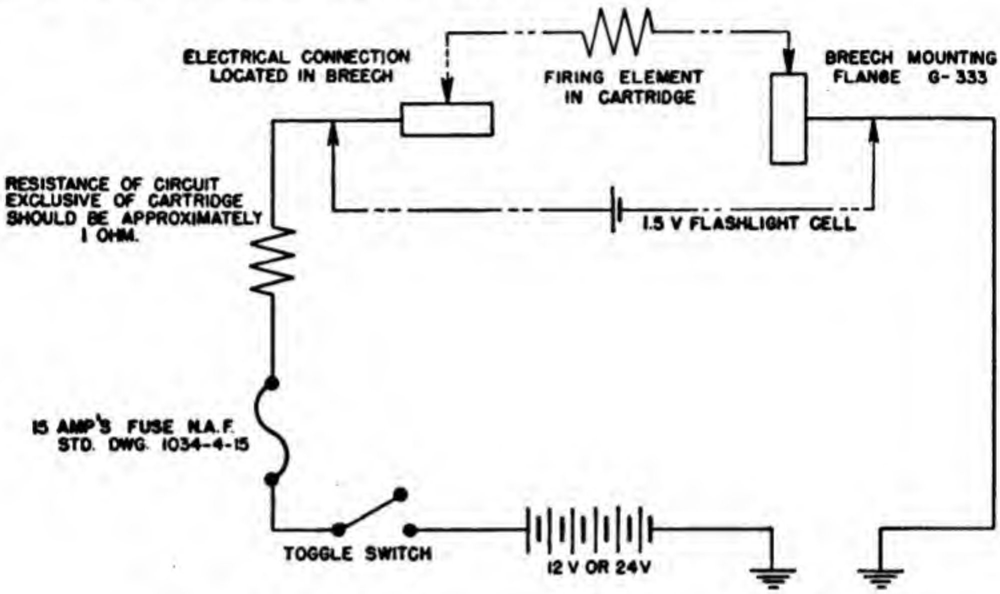


Figure 25.—Electrical diagram of cartridge type starter.

The toggle switch is a single-poled toggle type with a luminous tip on the toggle handle. It is installed on the instrument panel or at a location convenient to the pilot. A toggle switch guard prevents accidental closing. The switch is wired through the ignition in order to avoid unintentional operation.

The breech should be tested electrically after assembly. A magneto type circuit tester is a convenient device for detecting grounds and shorts. A metallic plug, shaped similarly to the cartridge base, is placed in the breech barrel. The breech is closed. An electrical indicating device, such as a lamp and battery circuit tester or other available

testing equipment, should be connected to the breech barrel by means of one terminal. The other terminal should be connected to the insulated wire extending from the flexible shielded conduit assembly. When the breech-opening lever is in the closed position, the indicating device should register continuity of the electrical circuit. When the breech-opening lever is upward and the breech housing is closed, the indicating device should register an open circuit.

CHAPTER 3

IGNITION

THE CYCLE

When a battlewagon is laying down a continuous barrage, the gun crew is plenty busy—LOAD, CLOSE BREECH, FIRE, and OPEN BREECH. This goes on again and again. The continuous performance of an internal-combustion engine consists of a similar cycle of events—

Admission of fuel and air to the combustion chamber (LOAD).

Compression of the charge of fuel and air (CLOSE BREECH).

Ignition and burning of the charge (FIRE).

Expulsion of burned gases (OPEN BREECH).

Engines are classified according to the number of strokes required to accomplish the complete cycle of events. In a two-stroke cycle engine, the piston travels once in each direction—up once and down once—for an entire cycle. In the four-stroke cycle engine, the piston travels twice in each direction to complete a cycle. At present, most aircraft engines are the four-stroke cycle type.

The combustion chamber is located in the cylinder head. It contains an intake valve and an exhaust valve, used respectively for admitting fuel and expelling burned gases from the chamber. These valves are operated by action of a camshaft. In the carburetor the fuel is mixed with air in correct proportions for efficient burning. This mixture reaches the combustion chamber of each cylinder through a passageway, known as the intake manifold. Burned gases are expelled through a similar passageway, known as the exhaust manifold. The burning gases expand rapidly and exert a tremendous force against the piston, which transmits the force to the connecting rod attached to the crankshaft. And the crankshaft translates the up-and-down motion of the piston into the circular motion of the crankshaft. Attached to the crankshaft is the propeller.

When the starter motor engages, the piston is forced inward toward the crankshaft. Follow the action by studying figure 26. The space within the combustion chamber is increased by this action. The air in the chamber which was at atmospheric pressure, is given room to expand. The result of such expansion is a lowering of the pressure within the chamber.

During this movement the intake valve is open, but the exhaust valve is closed. The lowering of the pressure within the combustion chamber causes outside air, at atmospheric pressure, to flow through the carburetor into the combustion chamber. As the air passes through the carburetor, it takes along some fuel. This is the INTAKE STROKE. When the piston reaches the lower limit of its stroke, the intake valve closes and traps the gaseous mixture of air and fuel within the combustion chamber.

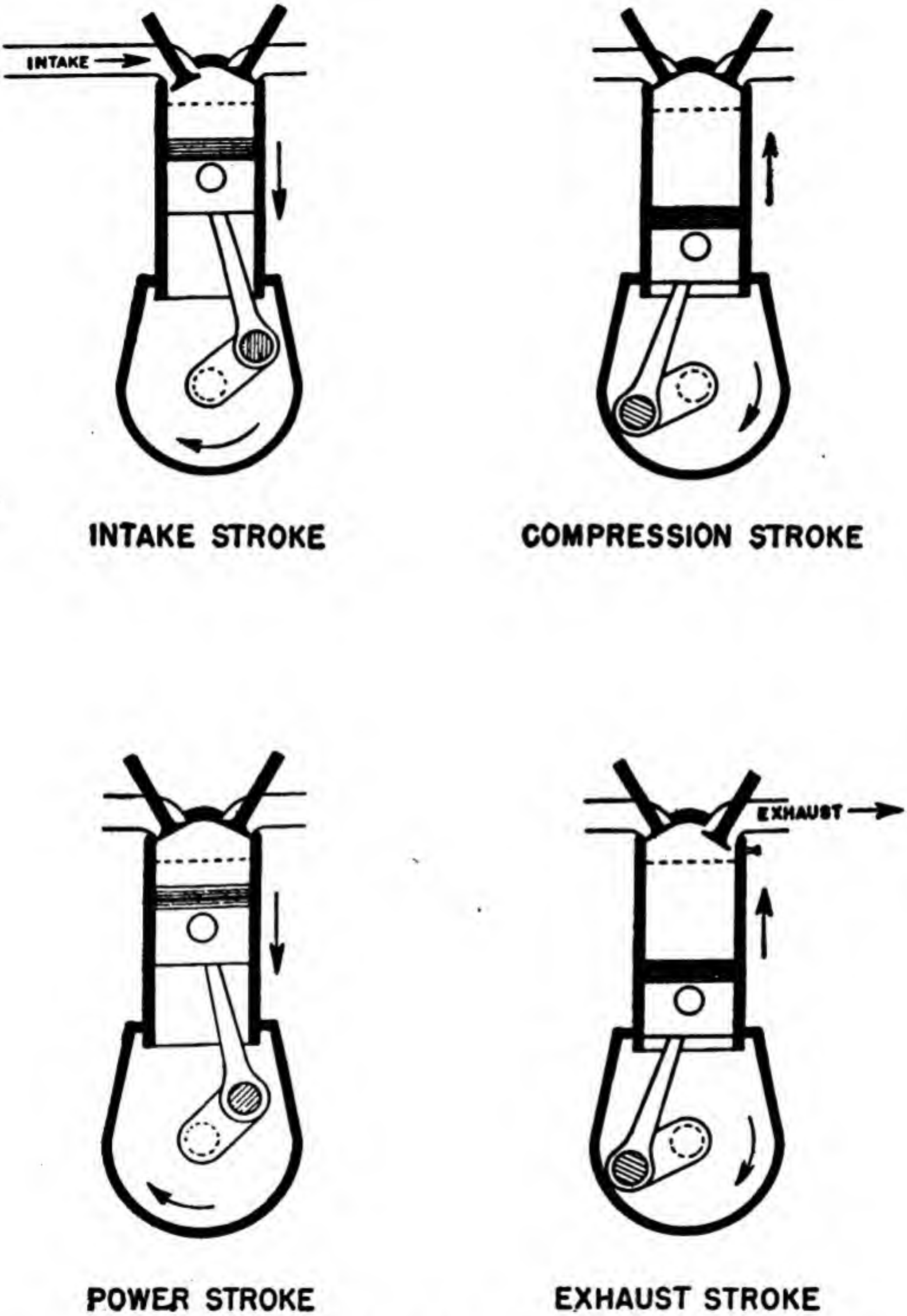


Figure 26.—Action in one cylinder during complete cycle.

Next, the piston moves outward, and the mixture becomes compressed. This is the COMPRESSION STROKE. At the final position of the compression stroke, the fuel and the air are highly compressed between the piston and the head of the engine.

At the appropriate instant, an electric spark passes across the terminals of a spark plug located in the chamber. The energy of the spark ignites the gaseous mixture. The temperature and pressure rise rapidly as the fuel burns. The gas, expanding as it burns, forces the piston inward and causes it to deliver mechanical energy to the crankshaft. This is the POWER STROKE. Both intake and exhaust valves are closed at the start of this stroke.

Because of the energy delivered to the crankshaft during the power stroke, the engine continues to rotate. The rotation causes the piston to move outward on the EXHAUST STROKE. The exhaust valve opens during the stroke, and the exhaust gases are ejected from the combustion chamber.

The preceding paragraphs have described briefly the action in one cylinder. Aircraft engines, however, are always multicylinder, the four-stroke procedure being followed in each. But all cylinders do not pass simultaneously through the sequence. While certain cylinders are operating on the power stroke, others are performing the compression, exhaust, or intake strokes. Thus, there is practically a STEADY FLOW of power.

The charge must be ignited at precisely the correct instant in the cycle, that is, just before the piston approaches the end of the compression stroke. Ignition at this exact moment permits the burning charge to attain maximum pressure before the piston starts its power stroke.

Sometimes the fuel mixture in the cylinder will be fired before the spark occurs. Such a condition is known as PREIGNITION. Any object inside the cylinder which is hot enough to ignite the fuel charge will cause preignition.

A charge, preignited, retards the outward movement of the piston, in the compression stroke and results in a loss of power. But this is NOT the only disadvantage of preignition. Preignition may cause most of the charge to be fired almost instantaneously so that the burning process becomes practically an explosion. This sudden rise in pressure produced a KNOCK. Even if only a small portion of the charge is exploded, there will be a slight PING. POWER IS LOST IN EITHER EVENT.

CARBON DEPOSIT in the combustion chamber is a common cause of preignition. Carbon retains some of the heat from previous power strokes. When the temperature of the carbon becomes high enough, it ignites a considerable portion of a charge during the compression stroke.

An IMPROPERLY SEATED EXHAUST VALVE also may produce preignition. Ordinarily heat produced in the valve is transmitted to the cooling system via the valve seat on the engine block. If the valve is not fitted properly, heat transmission is inadequate and the heat is retained. Burning gases "wipe" the valve which is quickly raised to a degree that will cause preignition.

Preignition occurs whenever the spark plug operates at a temperature high enough to set fire to the charge before the spark occurs. This may happen if a plug that does not throw off heat quickly is used in a high compression engine—that is, an engine that operates at high

temperature. Overheating of the plug may also be caused by hot gases "wiping" the plug as they pass through a leak in the plug.

A METALLIC BURR left on unfinished parts of the combustion chamber can also be a source of trouble. A thin edge of the burr becomes heated during one compression stroke and does not cool sufficiently before another begins. Preignition may also be caused by a HOT-SPOT in the cylinder head. Such a spot becomes overheated because of inadequate heat transmission from the chamber to the cooling system. Look for ANY ONE of these causes when you hear a knock or ping.

DETONATION

Not all knock or ping in an engine is produced by preignition. A high compression engine designed for use with a superior fuel will knock when used with inferior fuel. Knock will occur even though all mechanical features of the engine are in perfect condition. This type of knock is referred to as DETONATION.

Detonation occurs whenever the fuel charge or any considerable portion of it is ignited INSTANTANEOUSLY. Under normal conditions when the fuel is ignited by the plug the flame progresses uniformly across the head of the piston. During this time the pressure and temperature of the gaseous mixture rises and energy is delivered to the moving piston. While the flame is progressing, the temperature of UNBURNED portions of the fuel also rises rapidly. If the fuel is of a type which begins to burn at relatively low temperatures (low flash point), the remaining charge may burn INSTANTANEOUSLY. The tremendous increase in pressure which occurs causes the knock. Tetraethyl lead and other compounds are added to gaso-

line to prevent this condition. These compounds raise the flash point of the fuel and cause the entire charge to burn completely at an even rate.

Preignition and detonation are similar in their effects and in their symptoms. They differ only in the fact that one occurs before normal spark—the other after normal spark.

IGNITION SYSTEMS

Gasoline engines require an electrical spark to start the fuel charge burning. The means by which this spark is produced is called the IGNITION SYSTEM. There are FOUR essential parts of an ignition system.

> A source of high voltage impulses, properly timed. In practically all aircraft engines, a MAGNETO is used for this purpose.
>
> A method of supply these voltage impulses to each engine cylinder, one at a time, in a predetermined order. This is accomplished by means of a rotary switch mechanism called a DISTRIBUTOR. Usually the distributor is located within the magneto housing and is then considered to be part of the magneto.
>
> Wires to conduct the voltage impulses from the distributor to the cylinders. These wires form a unit which is enclosed in conduit. The entire assembly is called the IGNITION HARNESS.
>
> A break in the circuit through which the high voltage impulses force a current in the form of an electrical spark. The device used for this purpose is called a SPARK PLUG. The spark, jumping across the terminals of the plug ignites the fuel charge in the cylinder.

The ignition system you see in figure 27 is a DUAL IGNITION SYSTEM. This means that two inde-

pendent ignition systems are employed instead of one. Dual ignition was originally introduced as a safety factor, the idea being that if for any reason a spark was not being produced at one of the spark plugs, the second plug would still fire the fuel mixture in that cylinder and the engine would continue to operate satisfactorily. As aircraft engines increased in size and speed, dual ignition became necessary from a standpoint of proper performance as well as safety.

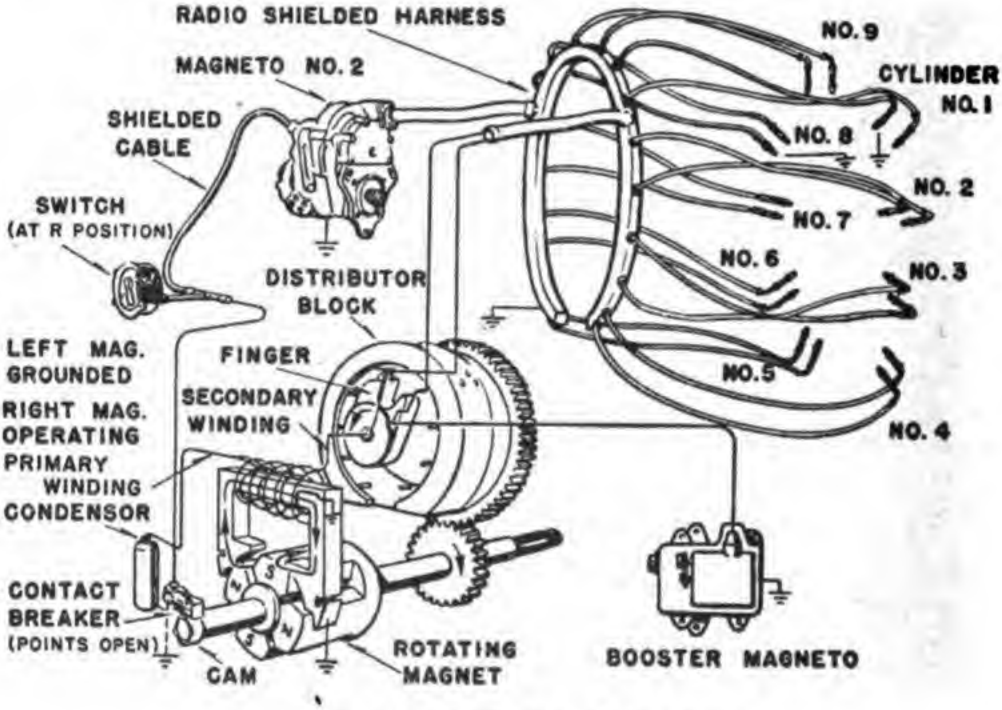
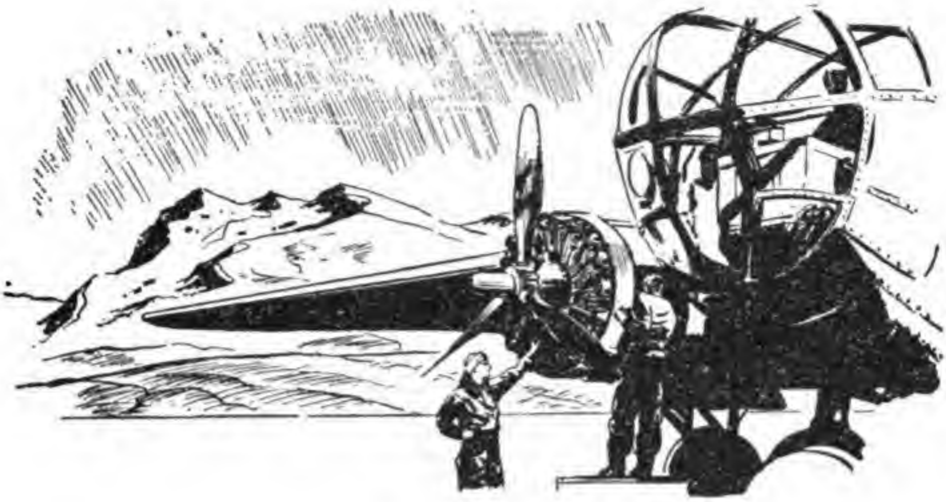


Figure 27.—Dual ignition system.

In dual ignition systems, the spark plugs are designated as FRONT or REAR (for radial engines). The front spark plug is mounted in the forward side of the cylinder. Magnetos are designated as RIGHT or LEFT, as viewed from the cockpit. The RIGHT magneto supplies current to the FRONT plugs; the LEFT magneto supplies current to the REAR plugs.



CHAPTER 4

MAGNETOS

HOW THEY WORK

A magneto is a modified form of an a-c generator, designed to produce short pulses of high voltage current.

As you know, a horseshoe or any permanent magnet has a magnetic field which is represented by many individual paths of invisible magnetic flux commonly known as "lines" of flux. Each "line" of flux within the magnet proper extends from the north pole through the intervening air space to the south pole, thereby forming a closed loop such as you have in figure 28.

The lines of flux have a natural tendency to seek the path of least resistance between the magnet poles. A laminated soft iron bar provides a much easier path for the flux than does air, and for this reason the lines will crowd together and pass through such a bar if it is placed near the magnet.

The "lines" of flux composing the magnetic field in figure 29 are shown concentrated in a defined path within the bar instead of occupying a large

portion of the air space. Therefore, the density of "lines" of flux within the bar is very high.

The direction of the flux in the laminated soft iron bar when placed in a magnetic field is determined by the polarity of the horseshoe magnet which is permanently magnetized.

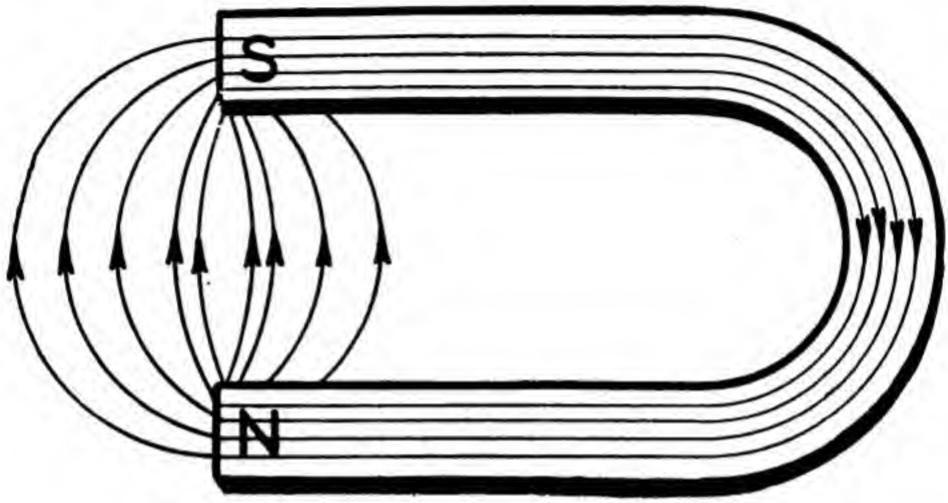


Figure 28.—Magnetic field of a horseshoe magnet.

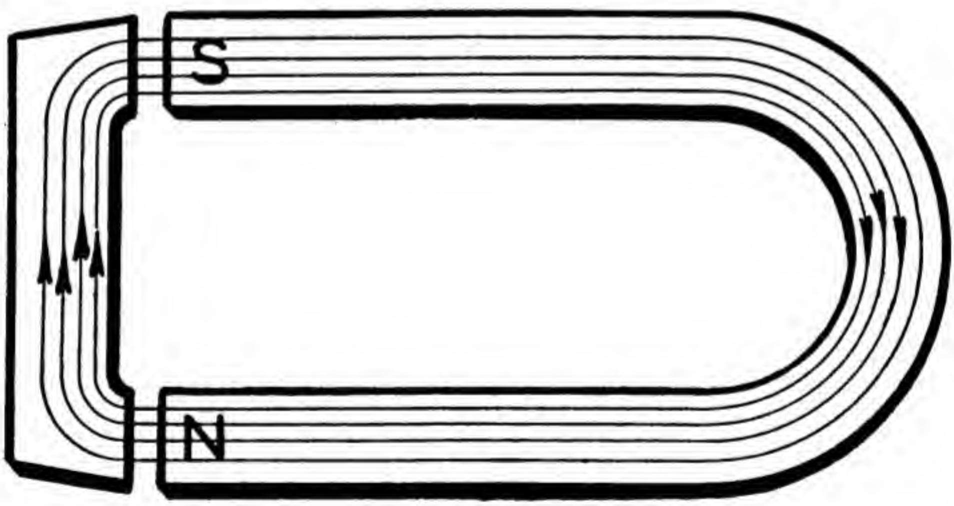


Figure 29.—Magnetic field of a horseshoe magnet with bar.

The laminated bar is of magnetically "soft" iron, which does not retain an appreciable amount of magnetism when magnetic lines of flux are passed through it. Therefore, should the horseshoe magnet in figure 29 be turned over so

that the north pole was at the top of the picture, the direction of the lines of flux would be reversed in the iron bar.

In order to induce a voltage in a conductor, you need a magnetic field and RELATIVE MOTION between the field and the conductor. To induce a voltage high enough to cause a spark to jump across the gap of the plug the conductor would have to be wound into a coil so large, that it would not be practical in an airplane. Or, the relative motion

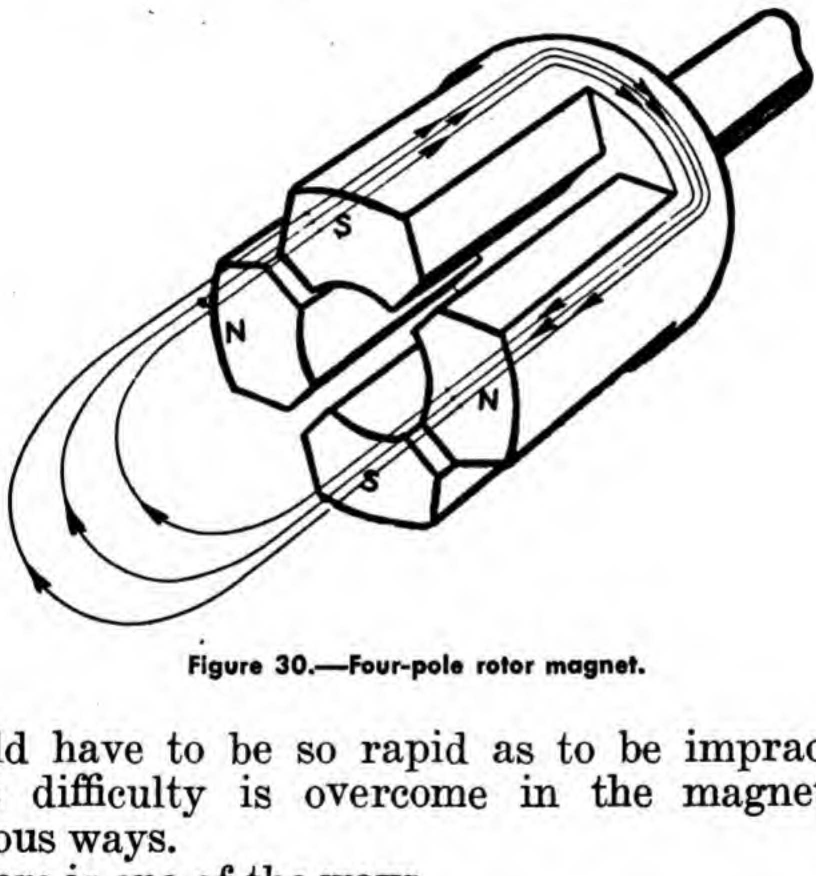


Figure 30.—Four-pole rotor magnet.

would have to be so rapid as to be impractical. This difficulty is overcome in the magneto in various ways.

Here is one of the ways.

A schematic illustration of a four-pole rotating magnet is shown in figure 30. The lines of flux of the rotating magnet, when not installed in the magneto, pass from its north pole through the air space to its south pole as indicated. This closely resembles the magnetic field of the horseshoe magnet shown in figure 28.

The pole shoes and their extensions are made of soft iron laminations cast in the magneto housing. The coil core, also made of soft iron laminations, is mounted on top of the pole shoe extension.

Note that no primary or secondary windings are shown on the coil core in figures 31 and 32. These have been omitted to permit a clearer description of the magnetic action. By first observing the

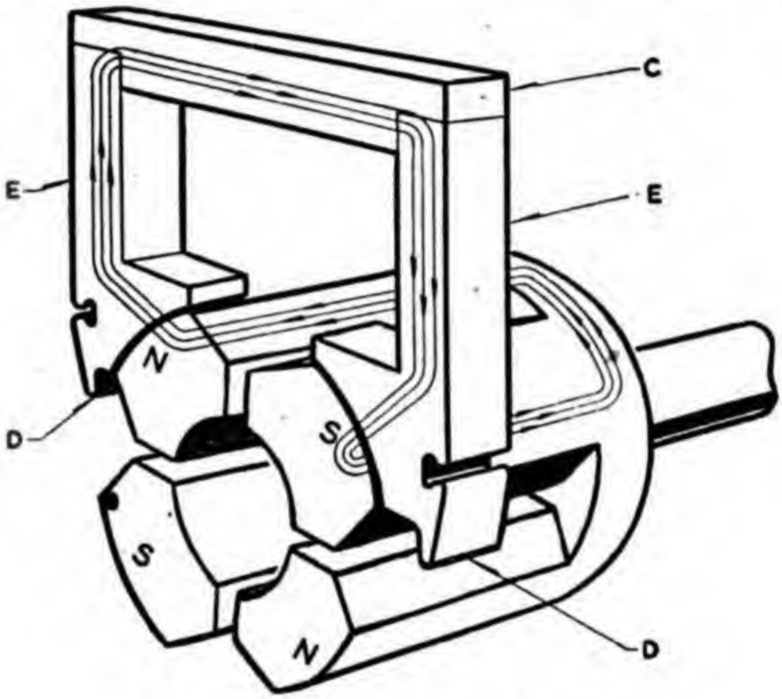


Figure 31.—Magnetic circuit of magneto.

action without the windings, you can later obtain a better understanding of their function in the magneto.

The pole shoes (*D*) and their extensions, (*E*), together with the coil core (*C*) as shown in figure 31 form a magnetic path similar to that made by the laminated soft iron bar illustrated with the common horseshoe magnet in figure 29. This magnetic path produces a concentration of flux in the core of the coil when the magnet is in the position shown in figure 31.

The neutral position of any rotating magnet is that position where one of the pole pieces is centered between the pole shoes in the magneto housing (look at figure 32). When the rotating

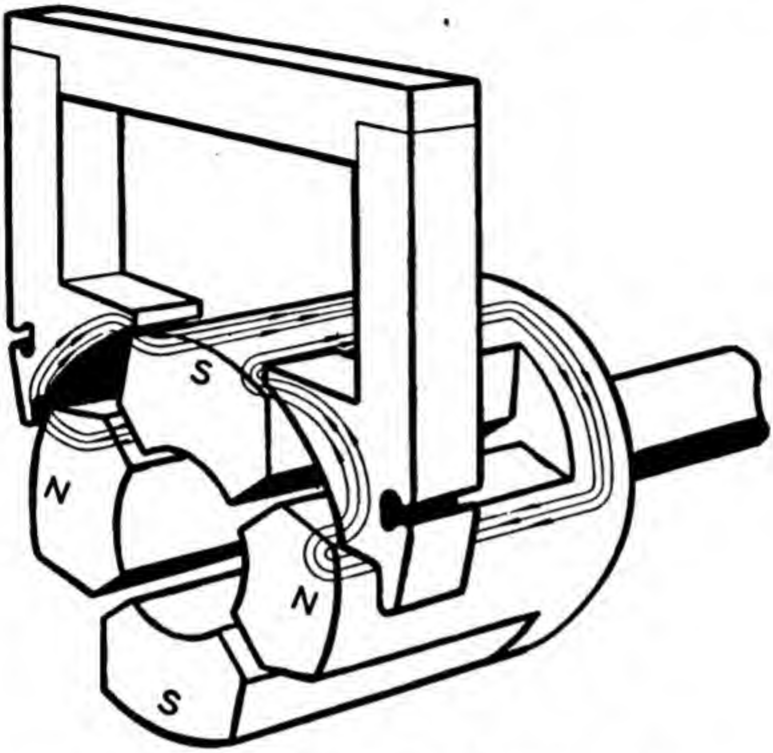


Figure 32.—Neutral position of magneto rotor.

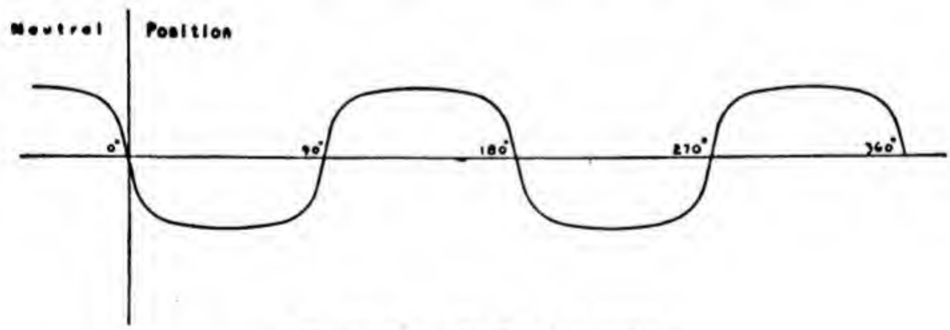


Figure 33.—Static flux curve.

magnet is in its neutral position, lines of flux do not pass through the coil core because they are "short-circuited" by the pole shoes.

The curve in figure 33 shows how the flux in the coil core changes when the magnet is turned with

no windings present. This is called the static flux curve, because it represents the normal or stationary condition of the circuit. If the magnet is turned with no windings on the coil core the flux will build up through the coil core in first one direction and then in the other as shown by this curve.

It is important to realize that this curve represents both the direction and the concentration of the flux. When the curve is above the line the flux is passing through the coil core in one direction. The higher the curve above the line, the greater the number of lines of flux in the core. The lower the curve goes below the line the greater the number of lines through the core in the other direction. Each time the magnet passes through a neutral position the flux in the coil core falls to zero and then builds up again in the opposite direction. Therefore the greatest change in flux occurs during the time the magnet is passing through the neutral position, as shown by the steep slope of the curve at the points corresponding to the neutral positions of the magnet.

The primary winding is made up of a comparatively few turns of heavy copper wire, and is wound directly around the coil core. When the magnet is turned through the neutral position, the flux in the core changes and induces a voltage in the primary coil.

The voltage induced in the primary causes current to flow in the primary coil. In turn, the magnetic field produced by the primary current, induces a voltage in the secondary. To induce a high voltage in the secondary coil, it is necessary that the rate at which magnetic lines of force cut the secondary be very high. In fact, higher than can be obtained by the action of the primary, by itself, on the secondary.

To accomplish this purpose, a mechanical circuit breaker is inserted in series with the primary coil. This breaker has two contact points which are closed or opened by the action of a cam which is geared to the magneto rotor, as shown in figure 34.

The cam is set so that breaker contacts close when there is maximum flux in the coil core.

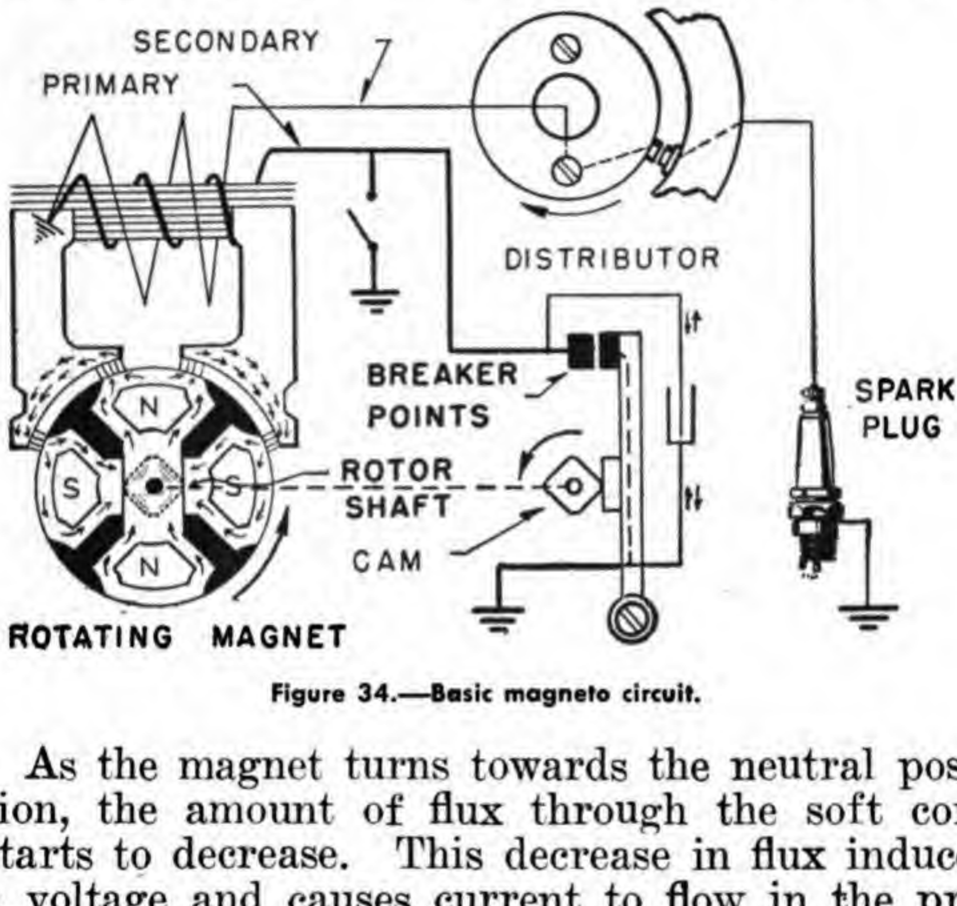


Figure 34.—Basic magneto circuit.

As the magnet turns towards the neutral position, the amount of flux through the soft core starts to decrease. This decrease in flux induces a voltage and causes current to flow in the primary coil. A current-carrying coil produces a magnetic field of its own. Accordingly, the current in the primary sets up a magnetic field of its own.

In accordance with Lenz's Law, this magnetic field opposes the change in flux which caused the primary current. This is shown graphically in figure 35. If no current were flowing in the primary, the flux in the soft iron would decrease to zero as the magnet was turned to the neutral

position, and then start to increase in the opposite direction, as represented by the "static flux" curve. However, the magnetic field set up by the primary current prevents the core flux from decreasing, as explained above, and temporarily stops the field in the core from changing direction. This is represented in the curve shown as the "resultant flux" curve (at the neutral axis point).

Now the primary current is maintaining the original field in the coil core, while the magnet has already turned past neutral and is now attempting to establish a field through the coil core

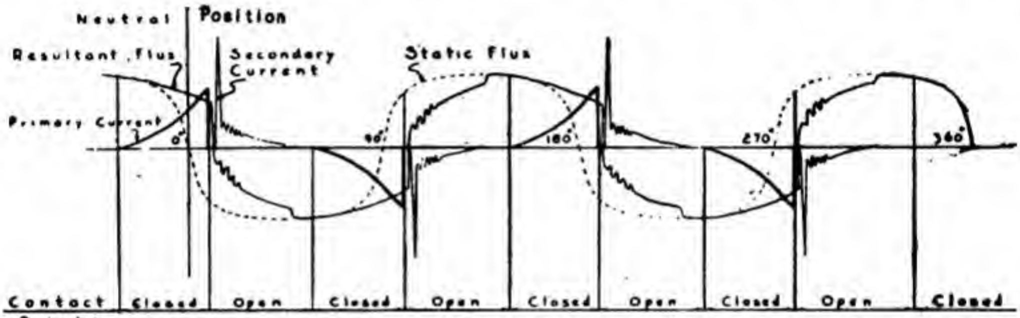


Figure 35.—Resultant flux curve.

in the other direction. A schematic illustration of the magnetic circuit at this instant is shown in figure 36.

This condition continues for a short interval until the moment when the breaker contacts are about to be opened by the cam. The interval, between the neutral position and the point of opening of the contacts is called the "E" gap. "E" gaps vary. However, for a representative type of four-pole magneto, it is 12°. "E" gap is also expressed as a distance past neutral.

Now, the primary current is maintaining the original field in the coil core, while the magnet has already turned past neutral and is now attempting to establish a field through the coil core in the other direction. A schematic illustration

of the magnetic circuit at this instant is shown in figure 36.

The contact points, when opened, break the primary circuit. This interrupts the flow of the primary current, causing an extremely rapid change in magnetic flux. In a very small period of time, the field set up by the primary current decreases to zero and is replaced by the field of

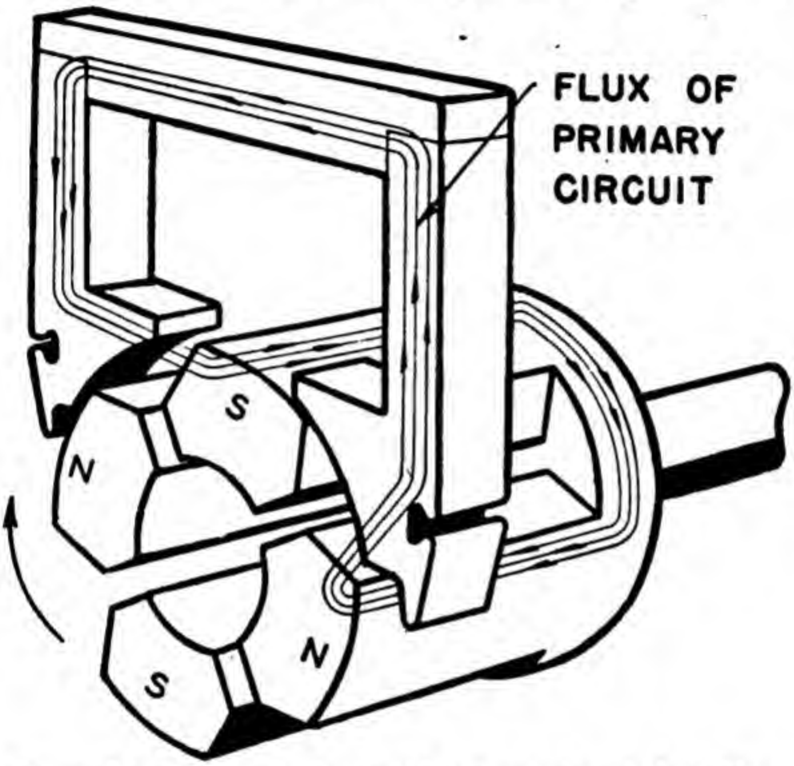


Figure 36.—Magnetic circuit with rotor past neutral position.

opposite direction set up by the rotating magnet. The process is represented by the nearly vertical part of the resultant flux curve shown in figure 35. You can see the flux reversed (just after the points open) in figure 27.

When the breaker contact points open and the magnetic field collapses, a very high voltage is induced in the secondary coil. The voltage produces the spark across the spark plug air gap.

A voltage is also induced in the primary coil. This would cause current to flow in the primary

and tend to make a spark jump across the breaker contact points. If such a thing happened, the SELF-INDUCED PRIMARY CURRENT would make the magnet flux change slowly instead of very rapidly—as it should in order to produce a high voltage in the secondary. And here is where the PRIMARY CONDENSER comes into the picture. With a condenser connected across the breaker, the self-induced current has another path to flow in, so that it doesn't try to arc across the contact points. And meanwhile the points have time to separate without a spark jumping the contacts. So you have a sudden break and a higher voltage in the secondary coil.

You may wonder what becomes of the charge in the condenser. Well, it does the same thing a charge would do in any condenser under the same circumstances. As soon as the voltage impressed across the condenser is reduced and is no longer great enough to hold the charge in the condenser, the condenser discharges through the primary winding. But this happens after the spark across the spark plug gap has started—so the effect is negligible.

To sum up the operation of the condenser, you can say that it absorbs the self-induced current of the primary. And here is the FINAL RESULT. It aids in producing a HIGHER VOLTAGE in the secondary coil. It makes the breaker contact points LAST LONGER because of less arcing.

The secondary winding, consisting of many turns of fine wire, is wound over the primary on the soft iron core. The large number of turns in the secondary together with the extremely rapid change in magnetic flux results in a very high voltage in the secondary coil. Figure 35 shows the current flowing in the secondary winding during the high voltage discharge.

When the high voltage in the secondary winding discharges, a spark jumps across the spark plug gap and ignites the fuel in the cylinder. Each spark actually consists of one peak discharge, after which a series of small pulsations occur (represented by the secondary current curve in figure 35) until the voltage becomes too low to maintain the discharge. During the time it takes for the spark to completely discharge, current is flowing in the secondary winding.

However, just as soon as current flows in the secondary winding, a magnetic field is set up which will oppose the change in flux which produces it. Therefore, the flux change is slowed up, as indicated by the tapering portion of the resultant flux curve.

In spite of the "slowing up" effect of the secondary current the spark becomes completely discharged, in the two- and four-pole magnetos, before the next "closing" of the contact points. That is, the energy in the magnetic circuit is completely dissipated by the time the contacts close for the production of the next spark. Study the "secondary current" graph in figure 35, where it will be seen that the resultant flux curve has tapered off so it exactly coincides with the static flux curve at the time the contact points close.

When current flows in the SECONDARY to produce a spark at the plug, a given time is required for the energy to completely dissipate itself—to clear the track for the next spark.

The more cylinders an engine has, the more sparks must be produced by the magneto for each engine revolution. Also, the faster an engine turns, the more sparks must be produced by the magneto within a given time. With engines of 14 or more cylinders operating at HIGH SPEEDS, the electrical energy in the secondary of the magneto

does not have time enough to dissipate itself—to clear the track—for the next spark.

Look at figure 37. You can see there that the resultant flux curve has not tapered off to coincide with the static flux curve by the time the contacts close.

When the contact points close, the energy remaining in the magnetic circuit is dissipated in the form of a change in flux as you see at "*P*" in figure 37. The flux change is in the opposite direction to that required for the primary current build-up of the next spark and, therefore, induces

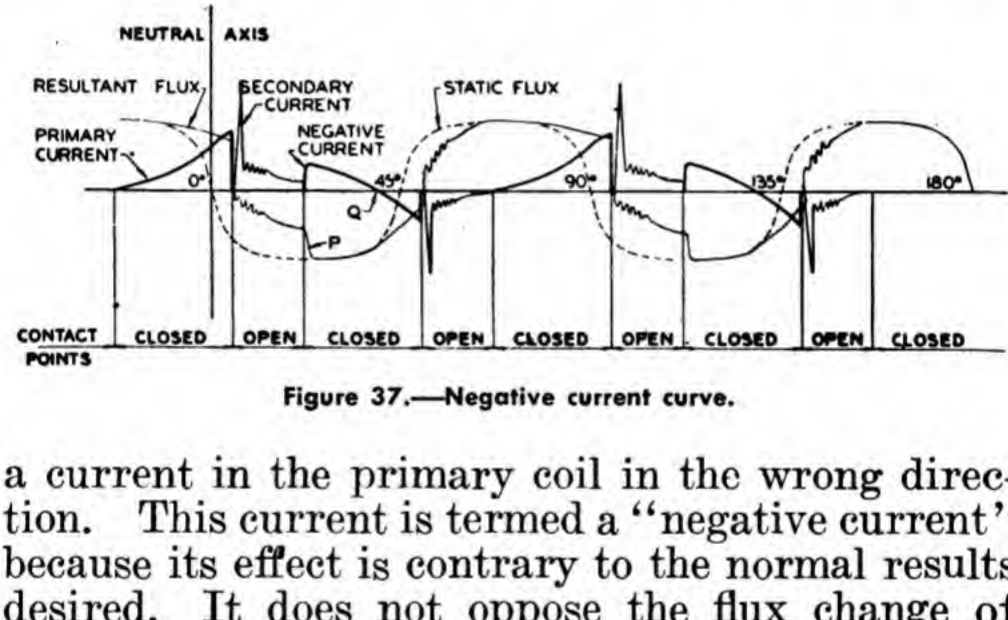


Figure 37.—Negative current curve.

a current in the primary coil in the wrong direction. This current is termed a "negative current" because its effect is contrary to the normal results desired. It does not oppose the flux change of the magnet. Therefore, during the time the negative current is flowing, little energy can be accumulated in the magnetic circuit.

As you can see in figure 37 the negative primary current finally reaches zero at "*Q*" after which a current in the proper direction is induced. However, the current is too weak to provide the required magnetic flux and so the succeeding spark is comparatively weak. Because of this, it will become completely discharged before the next contact point "closing." See the secondary cur-

rent curve in figure 37. The primary current builds up in the conventional manner, thereby producing a normal spark. The normal spark, however, does not have ample time to become completely discharged before the next contact point "closing," again causing a weak succeeding spark, and so on. Thus, you can see that every other spark produced will be comparatively weak.

To eliminate the "negative" current produced in the primary winding at high speeds, a condenser is placed in series with the secondary

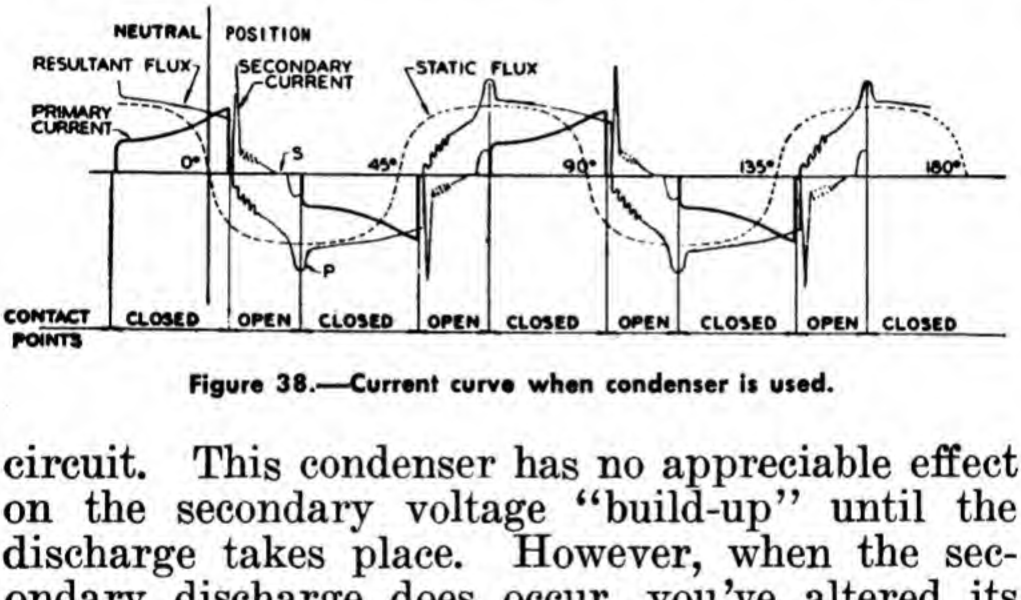


Figure 38.—Current curve when condenser is used.

circuit. This condenser has no appreciable effect on the secondary voltage "build-up" until the discharge takes place. However, when the secondary discharge does occur, you've altered its charactertistics. Compare the secondary current in figure 37 and 38 to see the difference.

Actually, the secondary condenser (also known as a "blocking" condenser) brings about a quicker decrease in the secondary current. Examine the point marked "*S*" in figure 38. After the secondary current has stopped, the condenser discharges back through the circuit in the other direction. Note the dip immediately following the straight line "*S*." The condenser reverses the magnetic circuit in such a way that when the contact points

close, the flux change "P" will be in the same direction as that required for the normal primary current build-up. This induces a current in the primary which adds to the normal primary current and causes all succeeding sparks to be of equal value.

One end of the secondary winding is grounded to the magneto. The other end terminates at the high tension insert on the coil. The high tension current produced in the secondary winding is then conducted to the central insert of the distributor finger by means of a carbon brush. From here, it is conducted to the high tension segment of the distributor finger and across a small air gap to the electrodes of the distributor block. High tension cables in the distributor block then carry it to the spark plugs where the discharge occurs.

The distributor finger is secured to the large distributor gear which is driven by a smaller gear located on the drive shaft of the rotating magnet. The ratio between these gears is always such that the distributor finger is driven at one-half engine crank-shaft speed. This ratio of the gears insures proper distribution of the high tension current to the spark plugs in accordance with the firing order of the particular engine.

Practically all aircraft engines operate on the four-stroke cycle principle. Consequently, the number of sparks required for each complete revolution of the engine is equal to one-half the number of cylinders in the engine. The number of sparks produced by each revolution of the rotating magnet is equal to the number of its poles. Therefore, the ratio of the speed at which the rotating magnet is driven to that of the engine crankshaft is always half the number of cylinders on the engine divided by the number of poles on the rotating magnet.

To understand more fully the operation of a modern aircraft magneto you must know about the compensated cam. You already know that aircraft engines operate on the four-stroke cycle principle. That is, the piston in the cylinder must make four strokes to complete the cycle. For the piston to go up and down once (two strokes) the engine crankshaft must make one revolution (360°). For the piston to complete the cycle then, the engine must make two revolutions (720°). In all four-stroke cycle engines the engine must make two revolutions to fire all the cylinders. This is true regardless how many cylinders the engine has. The more cylinders, the more power impulses per revolution of the engine. For a nine-cylinder radial engine, for example, all nine cylinders will fire in two revolutions of the engine. That is, the engine will have turned through 720°. So if all nine cylinders fire in this time, you would expect a cylinder to fire every 80° ($80\times9=720$).

This means that the magneto breaker points would have to open every 80° of engine crankshaft travel. An engine operating under these conditions would run well but its operation can be improved.

In RADIAL engines the spacing between the firing position of all the cylinders is not the same because of necessary engine design. In the nine-cylinder radial engine then the exact firing position of the different cylinders will vary by several degrees from the 80° spacing. Therefore, for ideal operating condition, the magneto breaker points must open a little before the 80° point for some cylinders, and after the 80° spacing for others. This calls for a special type of cam with

its lobes ground to compensate for the deviation from the 80° spacing for the special requirements of the individual cylinders. Such a cam is a COMPENSATED CAM. It is designed for individual types of ENGINES and not magnetos. Because each cylinder must be individually compensated for, the compensated cam must have as many lobes as there are cylinders. An 18-cylinder engine would have a magneto equipped with an 18-lobe cam designed for that particular engine. The General Electric magneto is an exception. Due to special construction only a nine-lobe cam is used.

Because the lobes of a compensated cam are not all the same, the correct one must be chosen in checking the internal timing of the magneto. The cam lobe used for this is always number 1, that is, the cam corresponding to number 1 cylinder on the engine. The number 1 cam lobe is always marked.

MAGNETO SWITCH

Magnetos are turned on and off with a switch, just like most other electrical devices. But the switch position for on and off is just the opposite of what it would be for most electrical circuits. To turn the magneto OFF you CLOSE the switch thereby providing a direct path to ground for the primary current. You OPEN the switch to turn the magneto on. This is a very important point for you to remember.

Look again at figure 34. When you close the switch to turn the magneto off, the current has another path to ground. Of course there is still a path through the breaker to ground. But you know that current will divide itself according to the resistance of the various paths. The more resistance in a given path the less current will

flow there. Most of the current will take the easier route. So in the magneto, most of the current will flow through the switch. Therefore, when the contact points open, the primary current is not interrupted. This prevents the production of high voltage in the secondary winding. Remember, to turn a magneto OFF you GROUND THE PRIMARY CIRCUIT by CLOSING the switch.

SCINTILLA MAGNETOS

All Scintilla magnetos use a rotating magnet to produce the necessary flux variations in the coil core. Figure 39 shows a single magneto. It has an 8-pole magnet and is used with 14-cylinder engines. Eight sparks are produced for each revolution. You may run into 4-pole magnets. They have to make two revolutions and travel twice as fast to produce 8 sparks in the same time.

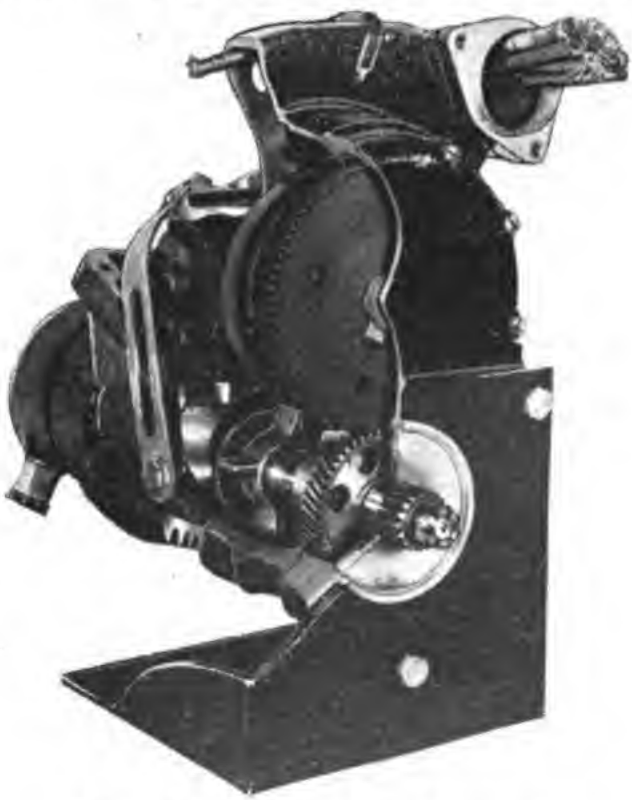


Figure 39.—Scintilla single magneto.

In figure 40 you have a DOUBLE MAGNETO. Really it is two magnetos in one except that there is only one drive and one rotating magnet.

The magnetic and electrical circuits of the double magneto are shown in figure 41. This magneto, which also employs an 8-pole magnet, is used with 18-cylinder engines. The two distributors are separate from the magneto.

Figure 40.—Scintilla double magneto.

There are various types of Scintilla magnetos but all are quite similar to either the single or double types mentioned here.

BOSCH MAGNETOS

Magnetos manufactured by Bosch are also constructed in the single and double types. The variation of flux in the coil core, however, is produced by the use of an INDUCTOR ROTOR and

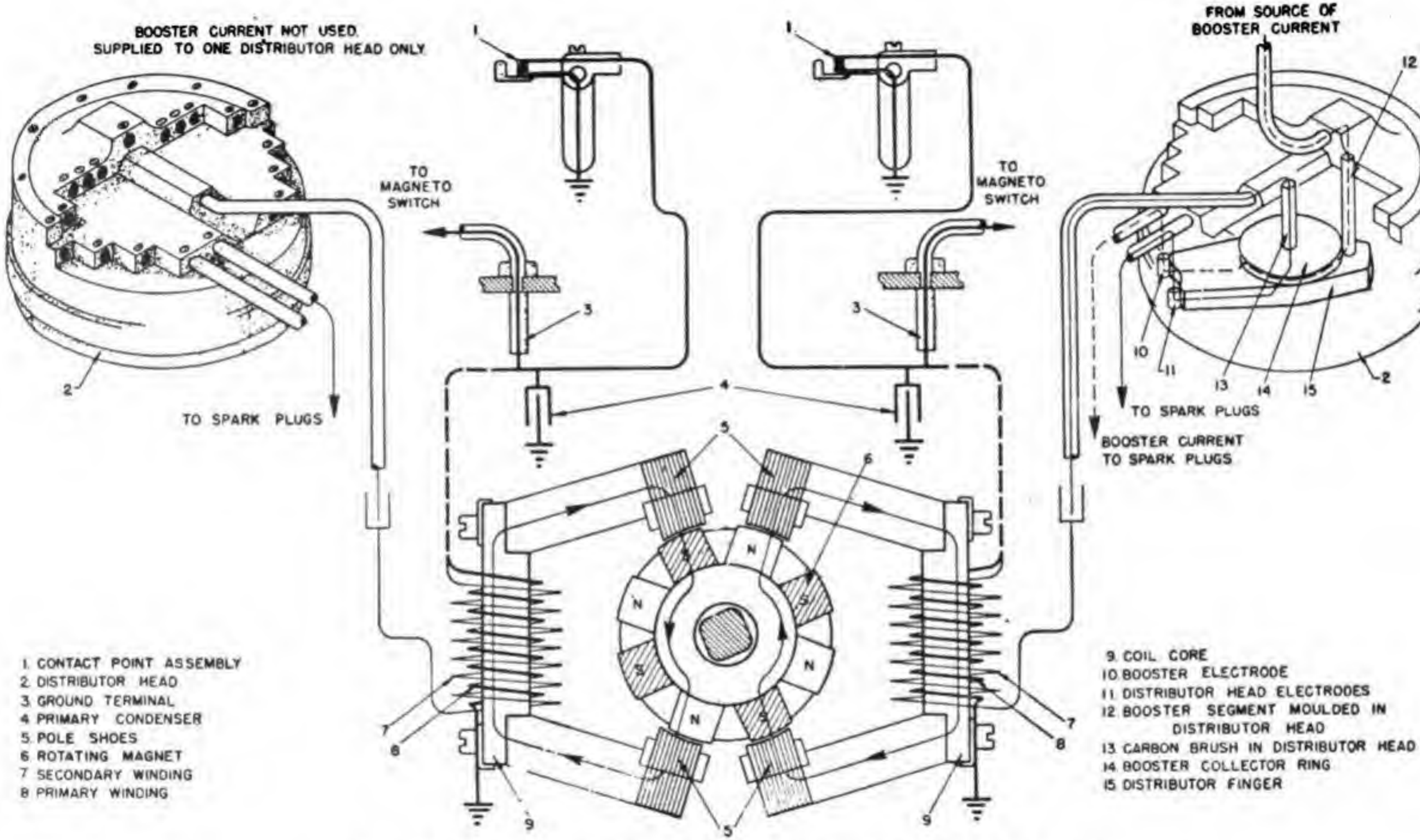


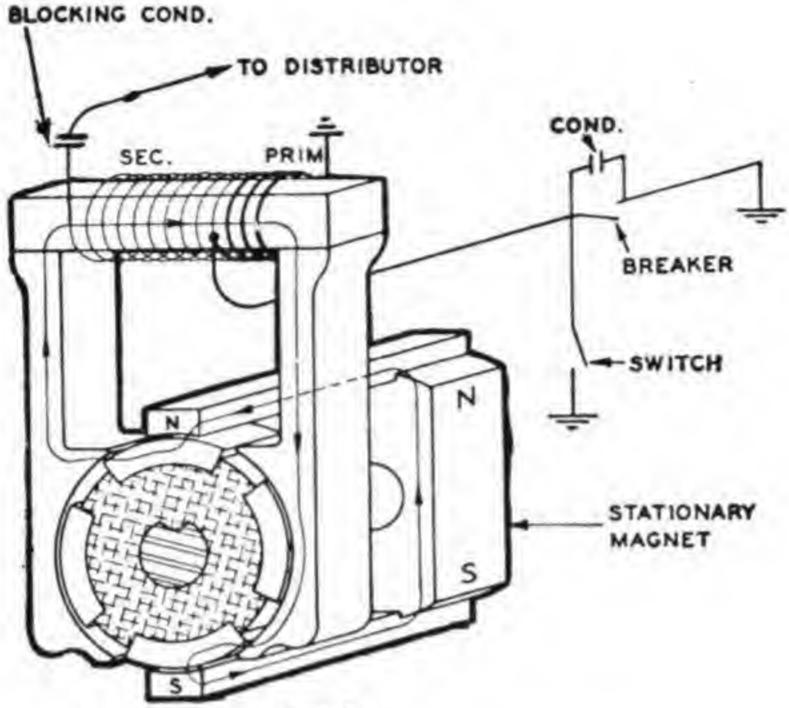
Figure 41.—Electric and magnetic circuits of the Scintilla DF1 8RN.

STATIONARY MAGNETS. Figure 42 is a photograph of a typical Bosch magneto.

In figure 43 you see the principal parts of a Bosch single type magneto. The rotor is made up of four sectors. (*A*) shows the flux thru the coil core. As the rotor is turned the flux will have to take a new route in (*B*). Here the flux is

Figure 42.—Bosch magneto.

flowing in the opposite direction. If you study the drawings further you will see that eight such flux reversals are obtained for each revolution of the inductor rotor. This means that eight sparks are obtained the same as with a rotating eight-pole magnet.



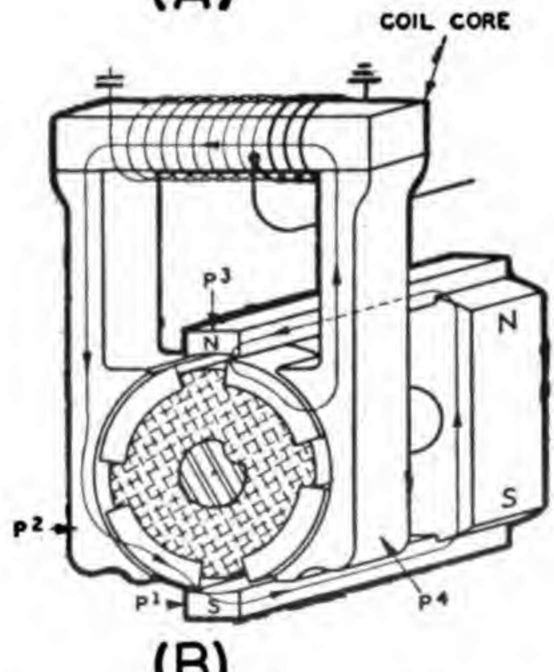


Figure 43.—Parts of Bosch single-type magneto.

Figure 44 shows the electrical and magnetic circuits of the Bosch double magneto. The solid flux lines show the magnetic flux as it exists when the rotor is in the position shown. The dotted

lines show the rotor in a position 45° later. Now the flux is in the opposite direction as indicated by dotted flux lines.

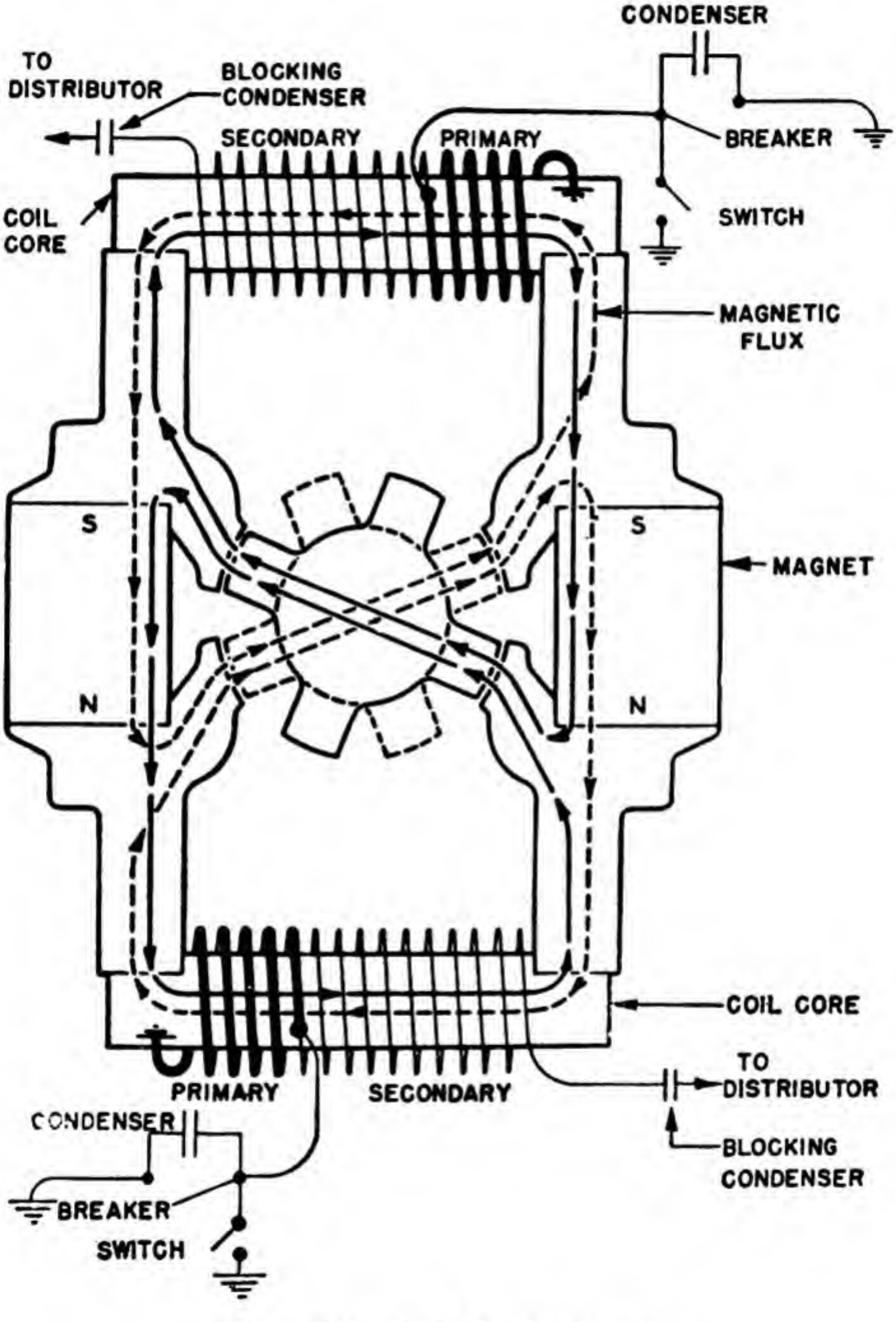


Figure 44.—Bosch double magneto.

GENERAL ELECTRIC MAGNETO
(S18LG–P1)

Designed for the R–2800 (18-cylinder) engine, the general principle of operation of the General Electric magneto is the same as for Scintilla and Bosch magnetos. However, you will find some variations in design and operation. The method employed to obtain the flux reversals in the coil core are similar to the method used by the Bosch magnetos. Look at figure 45.

(*A*) shows the flux passing thru the coil core in one direction. (*B*) shows that the flux has reversed itself by a small rotation of the inductor rotor. The rotor has 9 lobes. When it makes one revolution 18 flux reversals will have taken place making it possible to obtain 18 sparks: Therefore, one revolution of inductor rotor will produce enough sparks to fire all the cylinders of the engine.

The cam is a compensated cam with 9 lobes. Because two sets of breaker points are used, one revolution of the cam will produce 18-point openings for the 18 sparks. Each point will open 9 times per revolution of the cam making a total of 18 circuit interruptions. The breaker points are connected in SERIES. When one set of points opens, the other set must always be closed. For the current to build up in the primary circuit, both sets must be closed to complete the circuit.

AUXILIARY ENGINE STARTING METHODS

The ordinary magneto is highly satisfactory as a spark source for aircraft. However, it has certain disadvantages which show up in starting an engine. A magneto will only produce a satisfactory spark when it is driven AT or ABOVE a certain definite speed. This speed is called the "com-

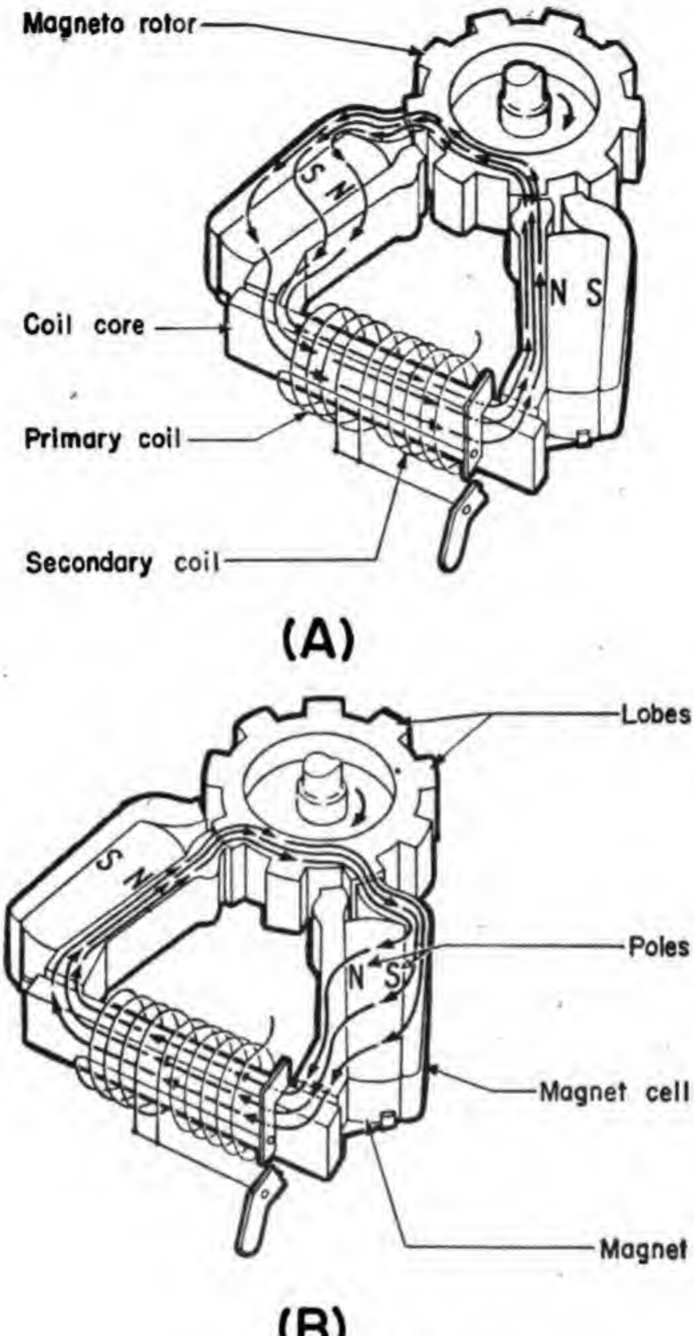


Figure 45.—G. E. magneto.

ing in" speed. At lower speeds the rate of flux change and emf induced in the magneto pirmary are insufficient for a proper spark.

When an engine is being cranked by a starter the engine speed is not high enough to reach the "coming in" speed of the magneto. For this

reason it is usually necessary to use some auxiliary device for producing a proper spark.

THE INDUCTION VIBRATOR

The latest device used with magnetos during the starting period is the induction vibrator. This unit produces a pulsating direct current which is fed into the primary winding of the magneto. Rapid flux changes are produced in the primary by this pulsating current. The result is a high secondary voltage.

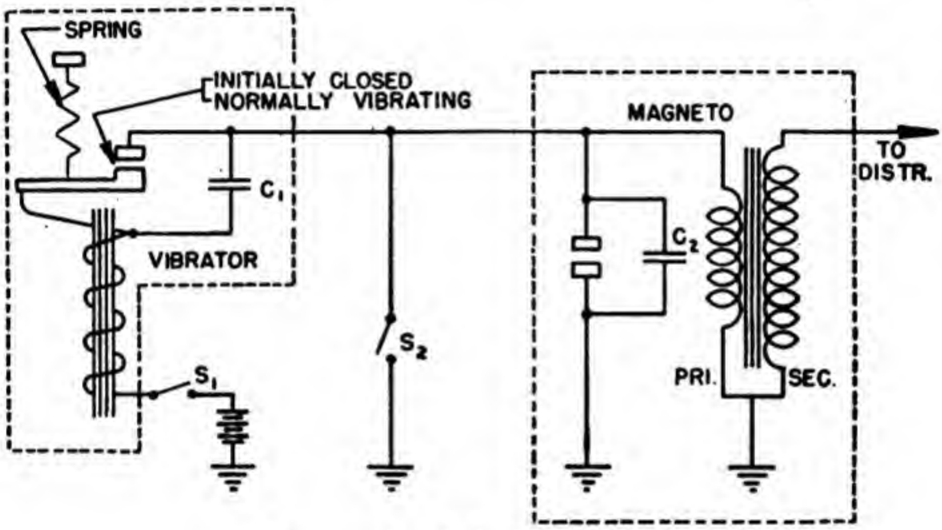


Figure 46.—Induction vibrator.

You will find the schematic diagram for an induction vibrator in figure 46.

When the switch at *S* is closed, current flows through the series circuit made up of the vibrator coil, vibrator contacts, and the primary circuit of the magneto. Current passing through the vibrator magnetizes the vibrator core and attracts the vibrator armature. This action separates the contacts and interrupts the current. The coil now loses its magnetism and the contacts are closed again by the action of the spring. This constant interruption occurs many times per second and

produces the pulsating current in the magneto primary. The pulsating current only flows through the primary when the MAGNETO breakers points OPEN. When these points are closed the pulsating current is shorted to ground through the points.

Now look at figure 47. It is the same as figure 46 except that the vibrator circuit is through the STARTER switch and the switch S_1. When the starter switch of an ELECTRIC INERTIA STARTER is thrown to the "ENGAGE" position, and switch S_1 is closed, the starter is connected to the engine which will begin to turn. This is when you need sparks in the cylinders.

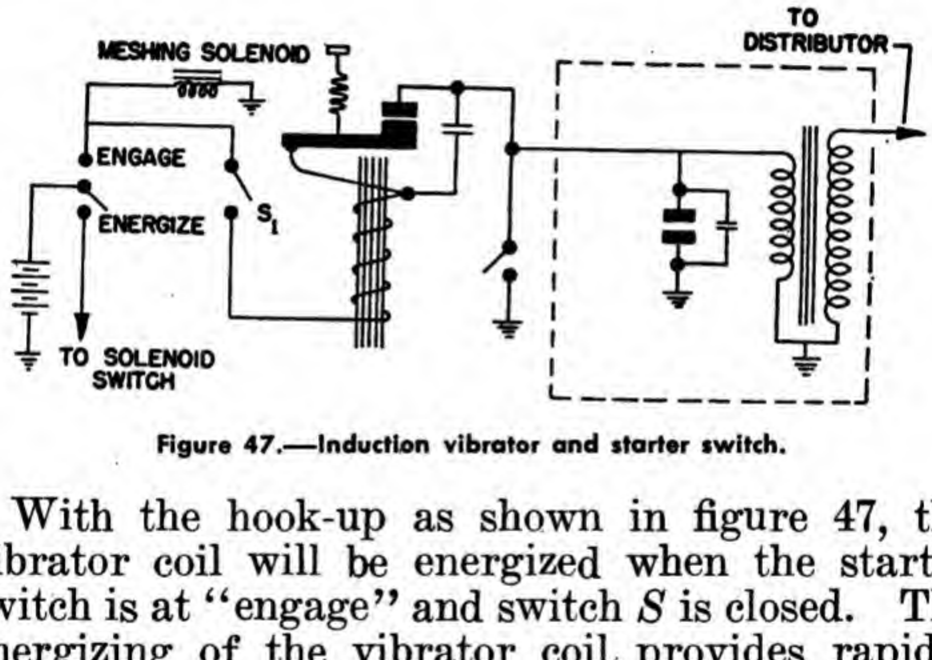


Figure 47.—Induction vibrator and starter switch.

With the hook-up as shown in figure 47, the vibrator coil will be energized when the starter switch is at "engage" and switch S is closed. The energizing of the vibrator coil provides rapidly pulsating current to the primary winding of the magneto and, in turn, sparks in the cylinders.

The starter switch is a toggle switch that automatically returns to a neutral (off) position as soon as you remove your hand from it. Thus you press on this switch to start the engine and as soon as it is started, you release the starter switch.

But with switch S_1 still closed, the magneto's primary is still grounded. This defeats the mag-

neto's efforts to produce sparks since this condition is the same as turning the magneto off. Switch S_1 must be opened at the same time that the starter switch returns to its neutral position.

In actual practice, an automatic switch or RELAY is used instead of switch S_1. This is shown in figure 48. Now, when the starter switch is thrown to "engage" the coil of the RELAY is energized. The magnetized coil core will now close the relay points thereby completing the circuit to the vibrator. When the starter switch is opened

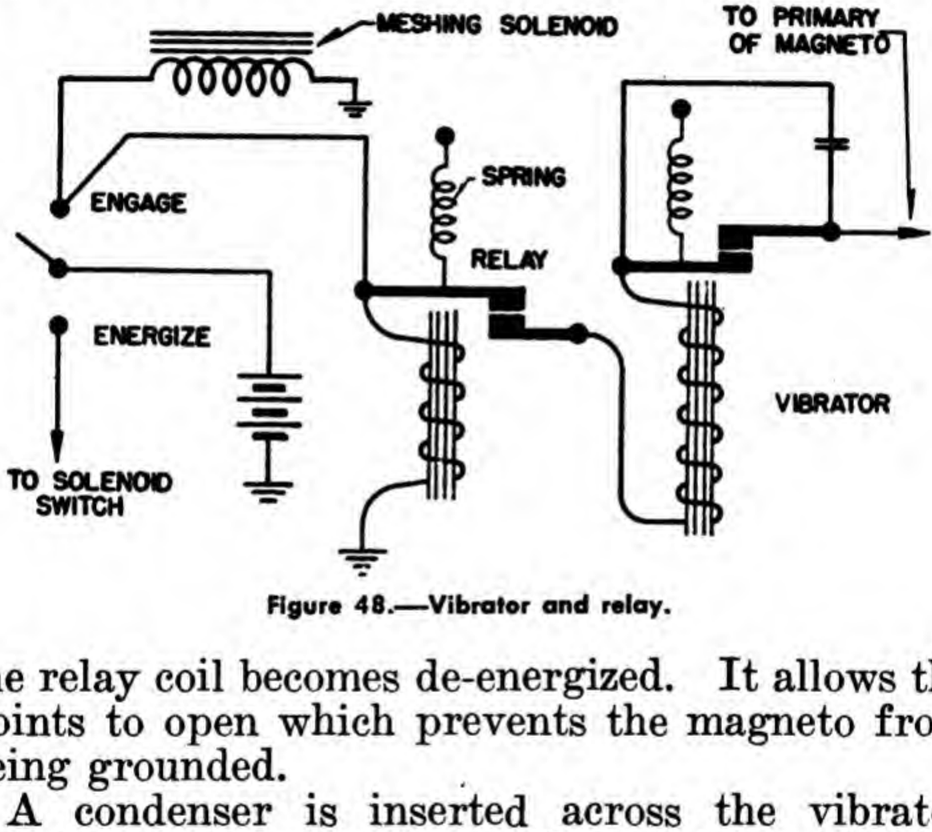


Figure 48.—Vibrator and relay.

the relay coil becomes de-energized. It allows the points to open which prevents the magneto from being grounded.

A condenser is inserted across the vibrator points to reduce arcing. The condenser fulfills this objective in the same way as the magneto primary condenser.

In the foregoing it has been explained how, with an ELECTRIC INERTIA STARTER, the relay prevents the magneto from being rounded out through the meshing solenoid. With cartridge or direct-cranking electric starters this would not occur.

The vibrator and relay are mounted in the same housing and this entire unit is referred to as the INDUCTION VIBRATOR. Only one induction vibrator is used for an engine, which means that with dual ignition systems only one set of spark plugs is fired for starting.

BOOSTER COIL

Another method of producing ignition for engine starting is to produce the high voltage independently of the magneto and then feed this

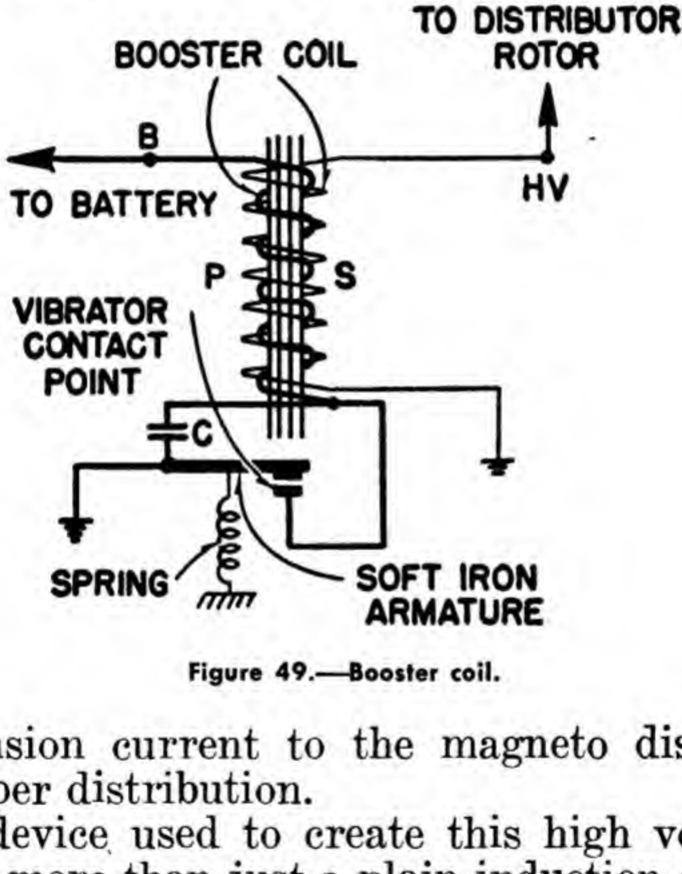


Figure 49.—Booster coil.

high-tension current to the magneto distributor for proper distribution.

The device used to create this high voltage is nothing more than just a plain induction coil. In aviation terminology it is called a BOOSTER COIL. In figure 49 you will see a schematic diagram. The coil has a primary and secondary winding. The vibrator points are in series with the primary circuit. The primary system is identical with the vibrator coil of the induction vibrator. This pri-

mary system again produces a pulsating current which, by induction, produces a high voltage in the secondary winding. The condenser serves the same purpose as the primary condenser in a magneto.

Only one booster coil is used for each engine which means that only one set of plugs are fired by the booster coil. It is the same operation you have with an induction vibrator.

The high tension current produced by the booster coil is fed to the magneto distributor system for proper distribution to the spark plugs. The magneto distributor is specially designed for this job. It has a special rotor with two fingers, one trailing the other. The trailing finger is used for the booster coil current. Look back at figure 27 for a moment and notice the two fingers on the distributor rotor.

CHAPTER 5

IGNITION HARNESS

CABLES

The group of cables that transmit the high tension current from the magneto to the spark plugs is called the IGNITION HARNESS. The ignition harness is completely enclosed in metal SHIELDING. This shielding offers excellent protection to the cables against mechanical injury and, also, a convenient means of securing the cables. But its chief purpose is to eliminate radio interference from the ignition system.

When a spark occurs in a spark gap, a sharp, dampened wave is produced and radiated a short distance, using the spark plug wire as an antenna. In Naval aircraft, every part of the ignition system that might possibly radiate electromagnetic waves (thus interfering with radio reception) is shielded completely by a metal covering.

The voltage required to produce a spark at the spark plug varies with different factors but may reach values between 10,000 and 15,000 volts. This demands exceptionally high-quality insulation. Most ignition cable has an over-all diameter

(including insulation) of seven millimeters. Hence it is referred to as "7 mm" cable.

Such cables are constructed of stranded, stainless steel wire. These strands are covered by a special type of rubber insulation. The rubber, in turn, is covered, for additional protection, with cotton fabric braiding which is impregnated against moisture. An airtight, lacquer coating is applied over the cotton for protection against moisture, oil, acids, and gases which might damage the insulation.

The rubber insulation used for ignition cable is also affected by ozone which is produced around the conductor. Ozone, a very active form of oxygen, is generated whenever air around a conductor is under high electrical stress. The lacquer coating is used to prevent contact between the ozone and rubber. It must be airtight to prevent this. Even a slight break in the lacquer coating may render the cable unfit for use in aircraft.

Ignition cable also deteriorates natural aging. Cable over 18 months old may not be used in Naval aircraft. The date of manufacture is determined by either of two methods. First, the date may be stamped on the lacquer coating, about every foot along the length of the cable. A cable stamped "2–44" means that it was made in February of 1944. A second method makes use of combinations of colored threads that are either inserted between the rubber and the cotton or are woven into the cotton braid itself. Where the colored threads are woven into the braiding, they are not always easily recognizable because the impregnation of the cotton braid dulls the colors. In this system of dating cables, 3 threads that may be colored by any one of four different colors are used.

Two of the three threads are always the same color and they denote the year of manufacture. The color of the third thread denotes the quarter of year of manufacture, in accordance with the following table:

YEAR		QUARTER		
red	1942	red	1st quarter	(Jan.–Mar.)
black	1943	black	2nd "	(Apr.–June)
yellow	1944	green	3rd "	(July–Sept.)
green	1945	yellow	4th "	(Oct.–Dec.)

The cycle of colors denoting the years is repeated every fourth year. Thus for 1946 the color will be red. For 1947 it will be black. And so on.

To determine the age of a cable threaded with two yellow threads and one green thread, simply note that the one green thread means the cable was made during the period from July to Sept. and the two yellow threads mean that the cable was made during the year of 1944. A cable coded with three black threads would have been made during the second quarter of 1943. If additional colored thread markers are found woven in the opposite direction to that of the date markers, they are the manufacturer's identification.

HARNESS SHIELDING

The harness shielding consists of a manifold ring, conduit, and spark plug elbows. You will see a manifold assembly in figure 50.

The manifold ring is cadmium plated brass. The conduit employed is usually flexible but airtight. Rigid conduit is sometimes used wholly or in part between the manifold and magnetos. At all joints where shielding units are connected together, gaskets are used to seal against moisture and guard against chafing of the cable insulation.

Shielding is only effective when grounded at many places. All shielding connections must be of very low resistance—not over a few thousandths of an ohm. Corroded or loose shielding connections

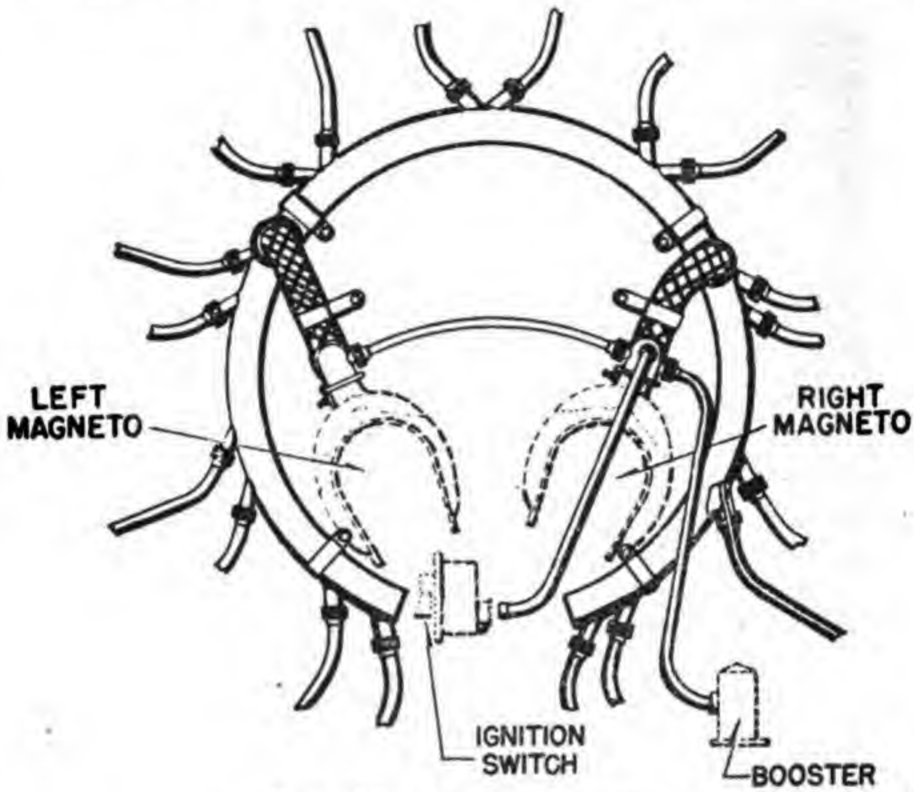


Figure 50.—Ignition harness.

will often result in radio interference from the ignition system.

IGNITION HARNESS TESTING

One of the most troublesome units of the aircraft electrical system is the ignition harness. Failure of the harness is generally caused by moisture and oil collecting inside the metal housing—and by abrasion. This weakens the insulation and affords opportunity for leakage of the high voltage to the case. All mechanical connections should be inspected frequently to insure tightness. Tight connections decrease the amount of oil and water that can seep into the harness shielding.

The COMMON METHOD OF TESTING HARNESS is to apply high voltage between the ignition wire and the shielding. A suitable indicating instrument, such as a neon tube, is placed in the circuit. The distributor blocks are removed before testing in order to prevent application of high voltage to the magneto elements. The flexible leads to the spark plugs are removed in order to prevent high voltage from jumping the spark gap, which would give a false indication. If the spark plug wires are left connected, any small charge of gas mixture in the cylinders will be ignited. They might result in possible injury to anyone in the vicinity of the propellers.

The HARNESS HIGH VOLTAGE TEST SET in figure 51 is designed to operate on 110 volts a. c., although its output is approximately 10,000 volts because of the action of the step-up transformer. The high voltage is sufficient to break down any part of the circuit that is defective.

The neon bulb is connected in the output circuit of the transformer. If a short exists in the ignition circuit, it completes the circuit to the op-

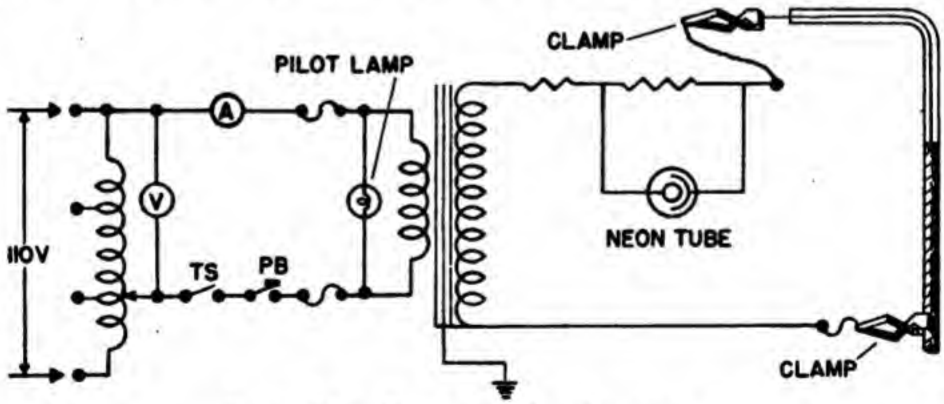


Figure 51.—Harness high-voltage tester.

posite side of the transformer. Hence, the neon tube will glow. If the insulation is satisfactory, the return circuit to the transformer will not be complete and the neon tube remains dark.

There are THREE leads attached to the instrument. In order to insure the safety of the operator, it is important that the leads be connected properly. Each lead is marked to indicate its purpose. The first lead to be connected is the GROUND LEAD. This must be secured to a good ground such as a water pipe or the steel deck of a ship. The second lead is connected to the ENGINE GROUND. The best contact in this case is the ignition shielding. The third lead is clipped to the PARTICULAR WIRE which is to be tested. After the three leads have been properly connected the tester is linked to the 110-volt power source. Thereafter, the third lead may be attached in turn to each of the cables undergoing test.

The testing instrument is equipped with a voltmeter and a variable reactor. The reactor insures operation of the device at the correct input voltage. The ratio of the step-up transformer is rather high so a few volts change in the primary voltage will change greatly the output voltage. The change may be sufficient to break down a good harness.

TAKE FLASH READINGS. DON'T KEEP THE TESTER TURNED ON FOR ANY GREAT LENGTH OF TIME. Frequently, an ignition system will withstand flash readings but will break down completely if subjected to the tester for more than a few seconds. This is particularly true when there is moisture in the system. The continued application of a high voltage across a system that has broken down forms a carbonized track. Consequently, what might have been a minor breakdown becomes a major one.

NEVER TEST THE IGNITION SYSTEM UNTIL YOU HAVE REMOVED THE DISTRIBUTOR BLOCKS AND HAVE DISCONNECTED THE SPARK PLUG WIRES.

It should be noted that the harness wire and its shielding is, in effect, a condenser. Therefore, when a. c. is used to test the harness, a small capacitive current may flow and give a false indication of defective insulation. To overcome this, you sometimes use d-c testers.

Although the ignition harness is a simple apparatus, it is very vulnerable to defects. Because of the high voltage involved, the current frequently finds a lower resistance path than across the spark gap at the plug. This condition is encouraged by the presence of moisture which is perhaps the greatest single element contributing to the poor functioning of a harness.

To improve harness operation, different types have been developed. One of these is the pressurized harness. This is quite similar to the type that has been described here except that air from the engine auxiliary blower is forced through the manifold ring and permitted to exhaust at each bottom end of the manifold. Another type of harness in present use is the plastic-sealed type. The cables are sealed in the manifold with a plastic material. The spark plug leads can be detached at the manifold. These leads are also sealed within the flexible conduit and you cannot remove them.

CONNECTING THE HARNESS

When connecting the harness to the magnetos and spark plugs the cables must be connected in the proper order or the engine will not operate. To facilitate this work the magneto distributor outlets are numbered in an orderly sequence—1, 2, 3, 4, and so forth. These numbers are referred to as magneto distributor numbers or simply MAGNETO NUMBERS. This sequence is the same order

in which the distributor rotor (finger) feeds current to these outlets.

Radial aircraft engines also have their cylinders numbered in an orderly sequence—1, 2, 3, 4—but the cylinders do not fire in this order. Below you will see the engine firing order of 9-, 14-, and 18-cylinder radial engines. It shows the sequence in which the cylinders fire.

9 cylinder 1-3-5-7-9-2-4-6-8
14 cylinder 1-10-5-14-9-4-13-8-3-12-7-2-11-6
18 cylinder 1-12-5-16-9-2-13-6-17-10-3-14-7-18-11-4-15-8

Since cylinder #1 fires first, distributor outlet #1 is connected to cylinder #1 by means of a conductor in the ignition harness. In the case of a 9-cylinder engine, magneto distributor outlet #2 must be connected to the cylinder that is to fire next. This would be cylinder #3. Similarly, distributor outlet #3 must be connected to the third cylinder to fire. In this case it would be cylinder #5.

Below, you can see the relationship between magneto distributor and cylinder numbers for a 9-cylinder engine.

MAG. FIRING 1-2-3-4-5-6-7-8-9
CYL. FIRING 1-3-5-7-9-2-4-6-8

In figure 52, you see a schematic diagram of the cables leading from the distributor to the various cylinders via the harness manifold ring.

LOW-TENSION IGNITION SYSTEMS

High voltage is required to force current through the high resistance offered by the gap at the plugs. This resistance is further increased by the high pressure in the combustion chamber. High voltage is difficult to handle in aircraft installations. It frequently finds short-cut paths to ground for the slightest reasons. Manufacturers

must go to great extremes to provide satisfactory insulation throughout the ignition system. Despite this, moisture will invariably creep in wherever possible and in seemingly impossible places. If you ever had an automobile, you are probably familiar with the effects of moisture on an ignition system. Waiting for the ignition system to dry out after a severe rainstorm is not a pleasant experience.

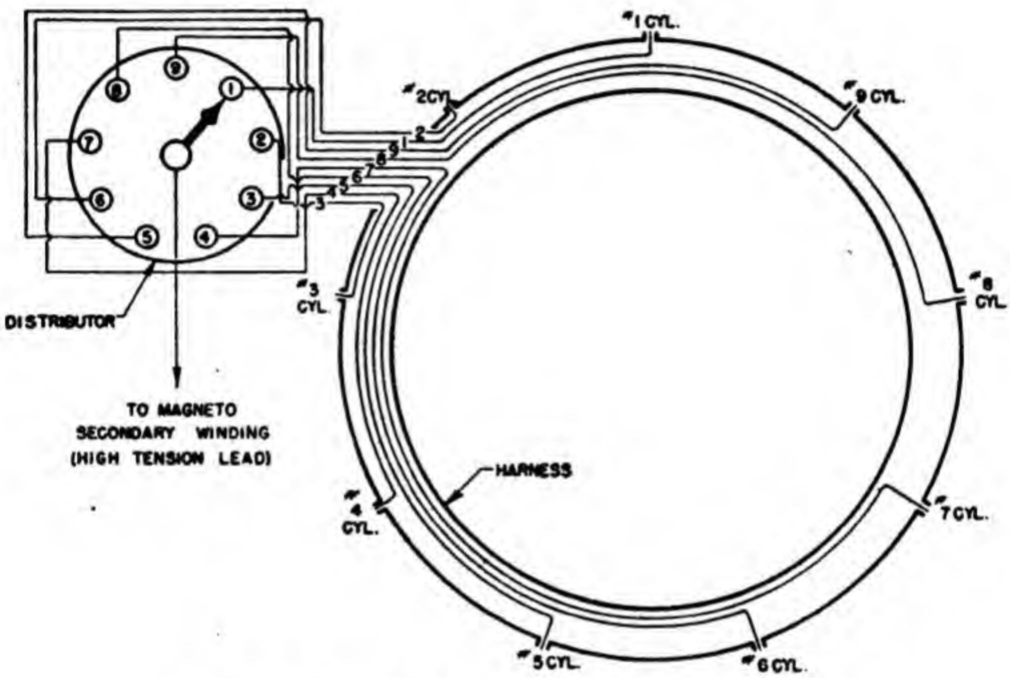


Figure 52.—Leads from distributor to cylinders.

Air pressure is another complicating factor in the problem of insulating for high voltage. At sea level where atmospheric pressure is 14.7 pounds per square inch, a definite amount of insulation is necessary to "hold" a definite amount of high voltage. At high altitudes where the pressure may be only 3.5 pounds per square inch, a greater amount of insulation is required. Therefore, it is quite possible to have satisfactory performance at sea level and ignition failure at high altitudes.

Manufacturers take great pains to carefully insulate the external parts of the ignition system. Nevertheless high voltage does cause break-down at these parts and an arc occurs. This is referred to as "flash-over." The current flow during "flash-over" is diverted from the spark plugs and accounts for ignition failure. To overcome its effect, certain magnetos are provided with pressurized chambers.

Low tension ignition systems attempt to localize these problems by generating a relatively lower voltage and distributing it through the harness. At or near the plugs the voltage is stepped up to the required value. With this arrangement, the greater part of the ignition system carries a reasonably low voltage and the insulating problem is made easier.

Low tension systems are not widely used at present, but a great deal of research work is being conducted on them. In the near future, a wider use of this system is quite possible.

CHAPTER 6

SPARK PLUGS

JUMPING THE GAP

The SPARK PLUG provides the small air gap across which the secondary current of the ignition system must jump in order to ignite the fuel charge compressed in the cylinder. The principle of the operation of the spark plug is quite simple, but only years of development have made possible the modern aircraft spark plug. This has been due to the fact that spark plugs in aircraft must operate under extremely high temperatures and pressures.

Spark plugs are of different types and kinds. One method of classifying spark plugs is based on the type of insulation used. You have two kinds, CERAMIC plugs and MICA plugs.

Figure 53 shows a sectional view of a ceramic plug. The ceramic material is an extremely hard type of porcelain. (A ceramic material is the type of material used in bricks, tile, etc.) This insulation material is very brittle and therefore extreme care must be taken in the handling of this type of spark plug. The chief structural parts of a typical ceramic spark plug are shown in the cross-sectional view. Current flows through a

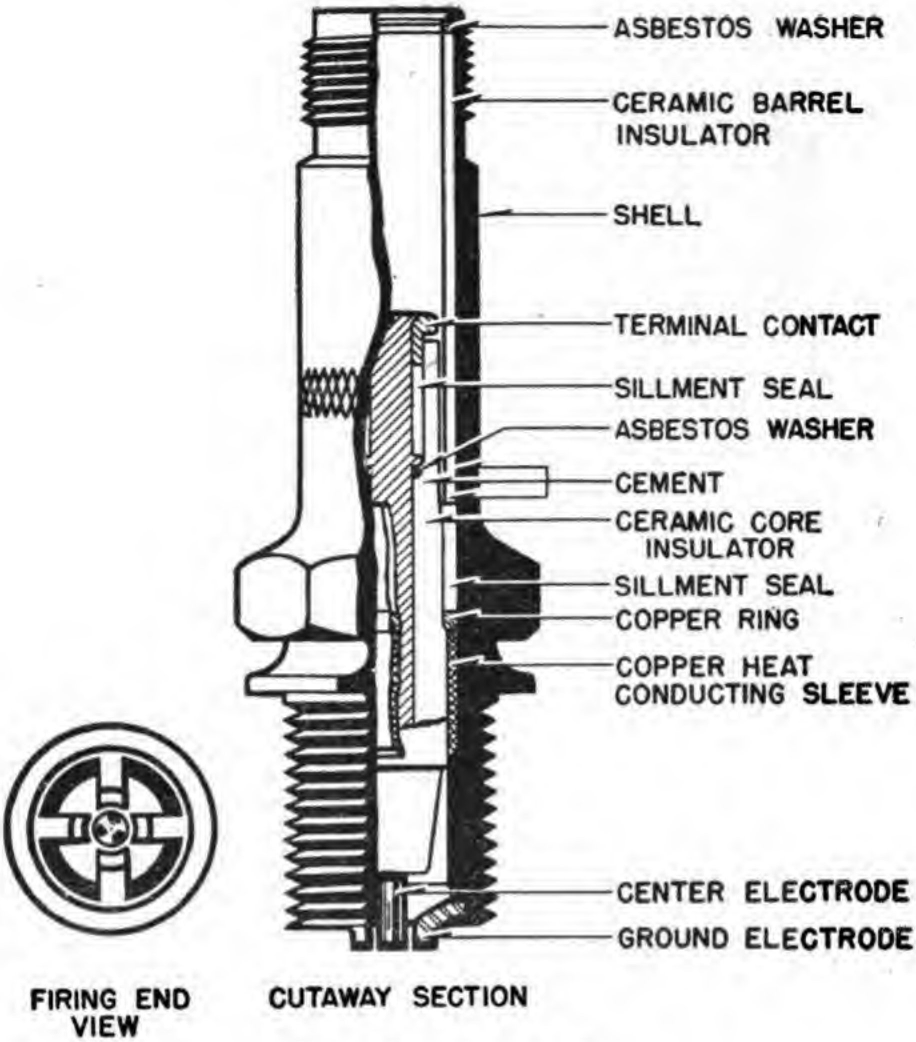


Figure 53.—Ceramic plug.

lead which makes contact with the TERMINAL CONTACT, through the CENTER ELECTRODE, across the gap, through the GROUND ELECTRODE, and then to ground.

Figure 54 shows a cross-sectional view of a mica plug and also the conventional method of connecting the ignition cable to the plug by means of a SPRING CONTACT SLEEVE.

Plugs pictured here are all SHIELDED plugs. The shielding is necessary to prevent radio interference from the ignition systems. Originally, all aircraft plugs were of the unshielded type. Such plugs look very much like automobile plugs.

When aircraft radio was first introduced and complete shielding of the ignition system became necessary, a metal hood was placed over the spark plugs. Such installations are rare today.

The spark gaps of a spark plug are formed by a CENTER ELECTRODE and GROUND ELECTRODES. The spark plug shown in figure 53 has four gaps. Some aircraft plugs have only three gaps. The current, however, does not divide itself at these gaps and produce several sparks at one time. Even though these gaps are adjusted to the same widths, one or the other will always have a little

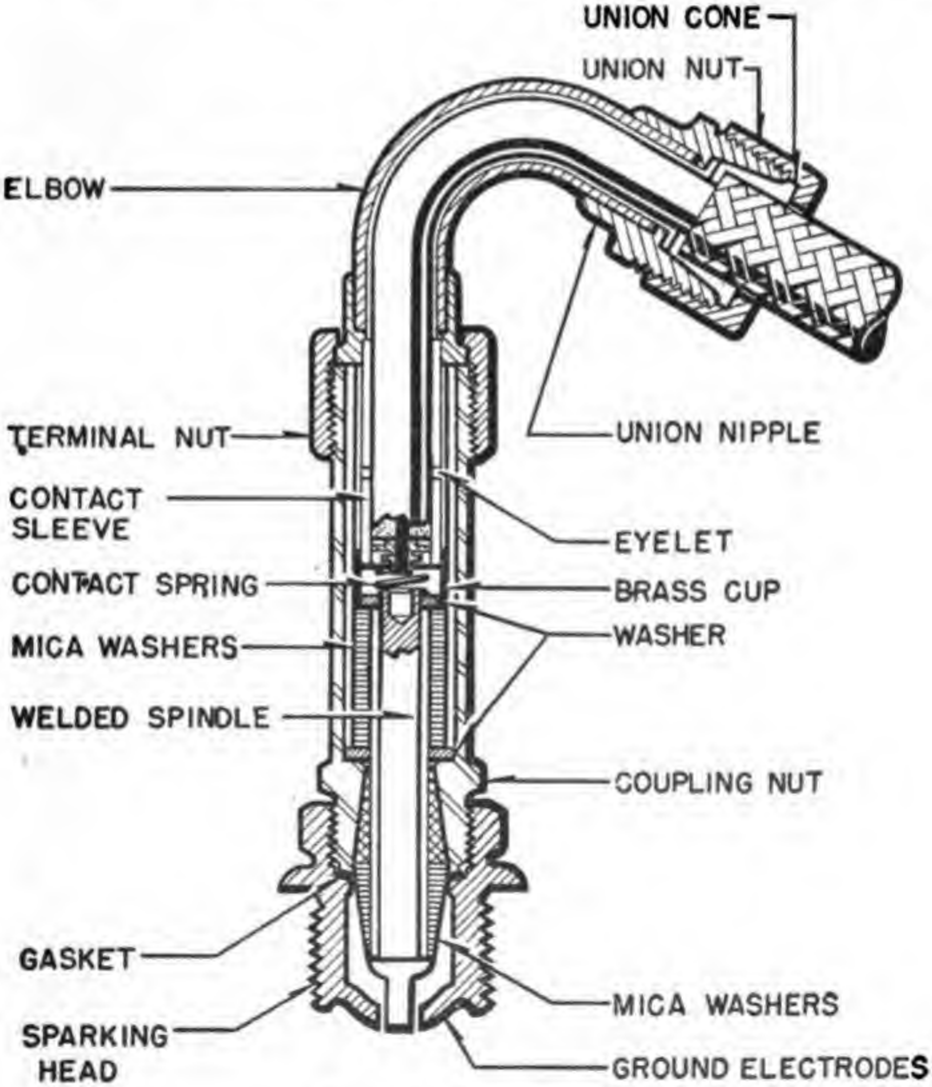


Figure 54.—Mica plug.

less resistance. The current takes the path of least resistance and only one spark is produced at a time. When the spark occurs, some of the metal at the electrodes is burned away. This spark gap will then have a resistance slightly higher than some of the others, so the next spark will occur across a different gap. This results in less wear for any particular electrode, thereby increasing the over-all life of plugs.

The operating temperature of a spark plug is very important. This temperature must be high enough so that oil, carbon, and lead compounds, deposited from the fuel will burn off. Otherwise, the current will be short circuited—it will find an easier path to ground—and no spark will be produced. When this occurs, the plug is said to be FOULED. On the other hand, the plug must not operate at too high a temperature. If it does it may become incandescent and preignite the fuel charge BEFORE the spark occurs.

PLUG TYPES

Different engines have different operating temperatures determined by cooling, compression ratio, and other factors. Spark plugs of different operating temperatures are constructed to meet the demands of the different engines. An engine that operates at extremely high temperatures requires a plug that will dissipate its heat quickly so that it will not become too hot and cause preignition. Such a plug is called a COLD RUNNING plug. Engines that operate at relatively low temperatures require a plug that will dissipate its heat more slowly so that the plug can remain hot enough to burn off combustion deposits that would cause fouling. This type of plug is a HOT RUNNING plug. Plugs for engines of intermediate

operating temperatures are MEDIUM RUNNING plugs.

The operating temperature of a spark plug is determined by its design. The chief factors are: the area of the core exposed to the flame in the combustion chamber; the area of the plug exposed to the outside air; and the rate of heat conduction through the plug material. On some spark

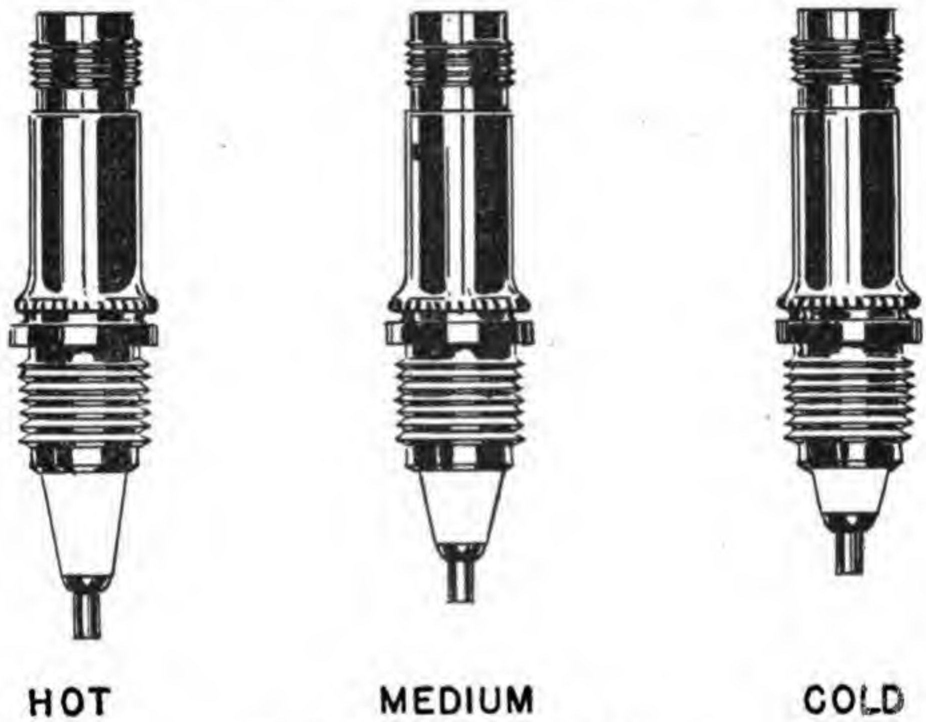


Figure 55.—Types of spark plugs.

plugs the area exposed to the outside air is increased with the aid of cooling fins. Figure 55 shows plug cores having different surface areas exposed to the flame in the combustion chamber. It should be noted that part of the heat is dissipated by the cylinder block via the screw threads of the plug.

SPARK PLUG FAILURE

Failure of spark plugs is mainly due to fouling, preignition, insulation failure, and burning of the

electrodes. Burning of the electrodes takes place, gradually, in every plug and results in widening of the spark gap.

In the Navy, spark plugs are reconditioned after every 60 hours of operation. The reconditioning involves: cleaning; gap adjustment; and checking for gas leakage and insulation failure. Mica plugs are disassembled in the reconditioning process, ceramic plugs are not. Ceramic plugs are cleaned by sand blasting with a special abrasive.

Spark plugs are subjected to very high pressures during operation and are susceptible to leaking at the joints. The object of the gas leakage test is to determine if the plug leakage is beyond allowable limits. An operation test is given all plugs by inserting them, one at a time, in a small airtight chamber and observing the sparking at 200 pounds per square inch. At atmospheric pressure the resistance of the spark gap is much less than at cylinder pressures. A plug may function perfectly at atmospheric pressure, but at operating pressure the path of least resistance may be through defective insulation rather than across the spark gap. Therefore, the plugs must be tested under pressure. The pressure chamber used for this test is often called a PRESSURE BOMB, and the test is referred to as the BOMB TEST. Dry air, or preferably carbon dioxide (CO_2) is used.

THE NAFOTEL TEST

Mica plugs are also given a special insulation test which is called the NAFOTEL TEST. The Nafotel test unit is similar to the high-voltage harness test set in that it is a high-voltage apparatus used to detect insulation failure. The output voltage of the Nafotel tester is impressed (across the insulated and grounded sides) of the plug core.

Current flow caused by this voltage is indicated by a neon lamp. The power source is the regular 115-volt a-c house current. Take a look at figure 56.

The mica insulation around the center electrode spindle is made up of mica washers. These are cemented together, compressed, baked, and machined. The expansion and contraction of the spindle due to temperature changes may eventually cause these mica washers to separate in places. This will allow lead and carbon deposits to become imbedded in the insulation and create

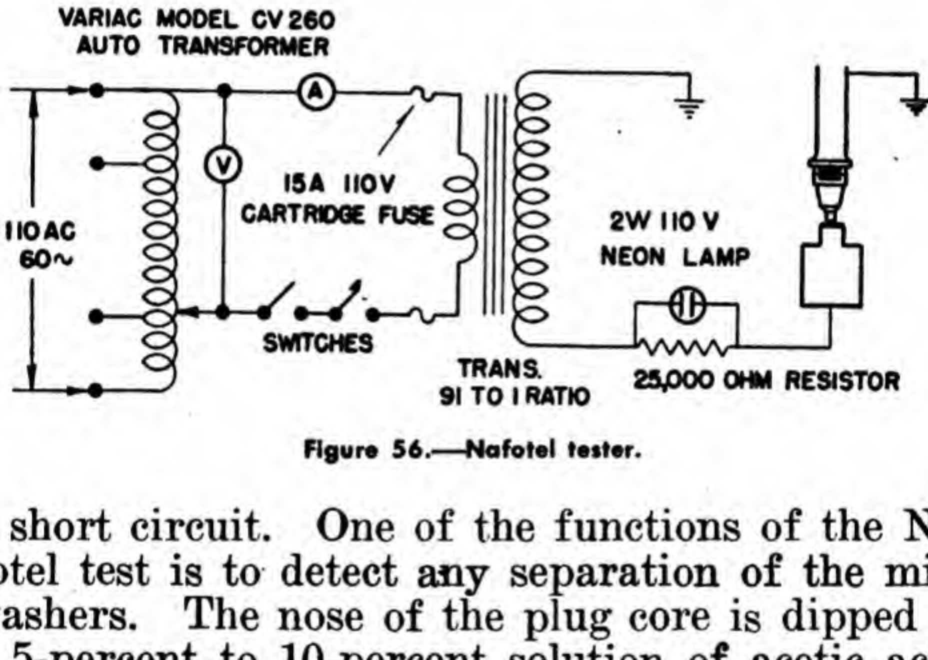


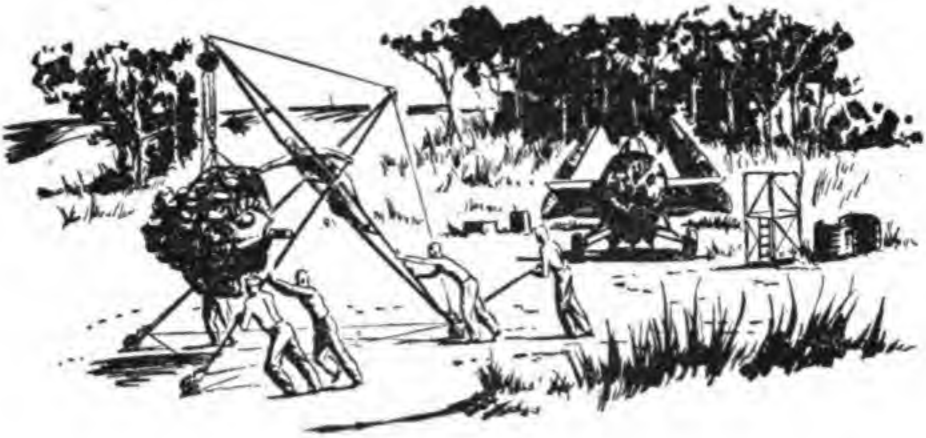
Figure 56.—Nafotel tester.

a short circuit. One of the functions of the Nafotel test is to detect any separation of the mica washers. The nose of the plug core is dipped in a 5-percent to 10-percent solution of acetic acid. The acid is immediately wiped off, and only that which has seeped into the cracks and crevices of the mica insulation remains. This remaining acid acts as a conductor when the high voltage is applied to the plug core, thereby aiding in the detection of insulation failures.

As has been previously stated, when current flows, due to the high voltage impressed across the plug core insulation by the Nafotel tester, the neon lamp will glow or flash. This frequently

happens when the plug insulation is not at fault. "Flashovers" at the plug insulation may occur due to various factors such as moisture and improper cleaning. It is therefore necessary to distinguish between APPARENT and TRUE FAILURES when applying the Nafotel test to mica spark-plug cores. Current technical orders should be consulted for necessary detailed information.

Because mica plugs are very susceptible to the absorption of moisture, the plug cores are baked before being subjected to the Nafotel test.



CHAPTER 7

AIRCRAFT POWER SUPPLY

STEADY DOES IT

In a long grueling race—like the famous 6-day bicycle races—each team has a pacemaker. He rides out on the track and leads the cyclists around and around the arena. If his speed is too great, the contestants who follow him are soon exhausted—BURNED OUT. If his speed is not great enough, he has not fulfilled HIS FUNCTION, and those who follow him are likely to be out of the race. The steady, even pace does it.

So it is with most electrical devices in aircraft. These devices are designed for operation on a fixed voltage. If the voltage applied is HIGHER THAN THE SPECIFIED VOLTAGE, the current through a device is increased in proportion. Under these conditions, the life of the device is reduced. If the applied voltage is more than 10 percent above the rated voltage, the device will probably burn out. This is particularly true in the case of lights.

When the applied voltage is LOW, no particular harm results, but the device operates less efficiently. If the voltage becomes too low, the device ceases to function. Therefore, constant

voltage within specific limits is an absolute necessity for efficient operation.

In aircraft during normal operation, the voltage of the electrical system is maintained by the generator and battery operating IN PARALLEL. The voltage of the system depends on the voltage of each unit. The voltage of the battery is sub-

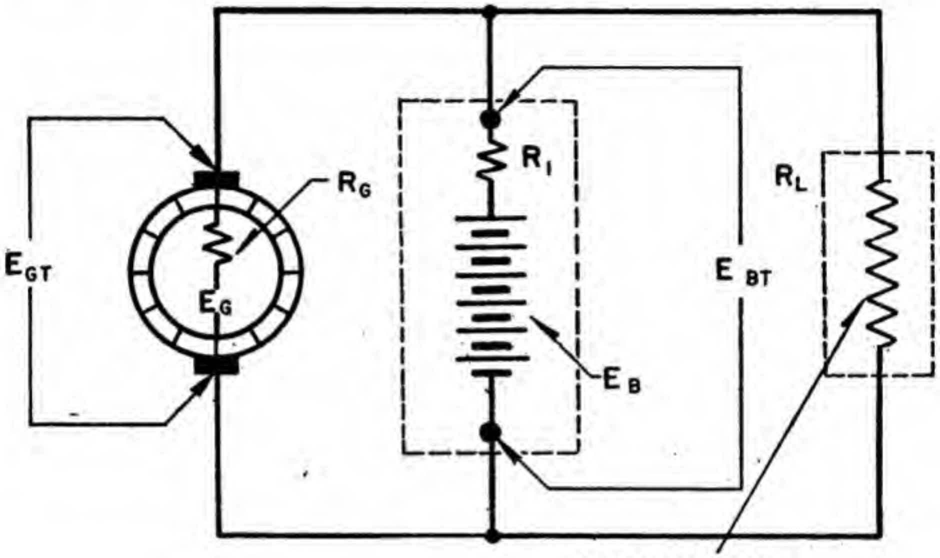


Figure 57.—Schematic diagram—Aircraft electrical system.

E_B	=Battery electromotive force	E_L	=Line voltage.
E_{BT}	=Battery terminal voltage.	R_G	=Generator armature resistance.
E_G	=Generator induced voltage.	R_I	=Battery internal resistance.
E_{GT}	=Generator terminal voltage.	R_L	=Load resistance.

stantially constant. The system voltage is principally affected by variations in the voltage of the generator.

An aircraft generator is driven by the engine. In the course of normal flight the speed of the engine varies widely. On account of this variation, the generator—coupled to the engine—rotates with variations in speed. Because the generator voltage output depends on the rotational speed, any variation in the speed complicates the problem of maintaining a constant voltage.

Figure 57 is a simplified schematic diagram of the principal units in an aircraft POWER SUPPLY SYSTEM. It is simplified because, for clarity, all switches and relays have been omitted.

The circuit is a simple one and the general operation can be understood if certain fundamental electrical principles are kept in mind. A complete understanding of the circuit requires a thorough knowledge of d-c theory. A knowledge of Kirchoff's laws is required in order to check the calculations.

From the standpoint of the load circuit, there is only one voltage present in the system. This voltage, hereafter referred to as the LINE VOLTAGE, is supplied by the two voltage units, the battery and the generator. Line voltage is determined by all the individual voltages present in the circuit and by the voltage drops that occur in various parts of the circuit.

In the generator, for example, an INDUCED VOLTAGE E_G is generated in the armature. When the generator delivers current, the GENERATOR TERMINAL VOLTAGE E_{GT} is less than the induced voltage by an amount equal to the IR drop caused by armature resistance R_G. THE DROP WITHIN THE GENERATOR INCREASES IF THE LOAD CURRENT INCREASES. Thus, when no CURRENT is being delivered, the generator terminal voltage equals the induced voltage. When the engine is not running, the generator does not function. The battery THEN is the only voltage source present in the circuit.

In the storage battery, the voltage produced by chemical action within the cell is referred to as the BATTERY ELECTROMOTIVE FORCE E_B. Whenever the battery discharges, the BATTERY TERMINAL

VOLTAGE E_{BT} is less than E_B by an amount equal to the IR drop across the internal resistance R_I of the battery. THE INTERNAL VOLTAGE DROP WITHIN THE BATTERY INCREASES AS THE DISCHARGE CURRENT INCREASES. When no current passes through the battery, the battery terminal voltage equals the battery emf.

Whenever the battery is charged, the opposite condition exists. A voltage drop is present across the internal resistance of the battery, but in this case it adds to the battery emf. Hence the BATTERY TERMINAL VOLTAGE INCREASES AS THE CHARGING RATE INCREASES.

A fixed voltage and a variable voltage both acting on the same circuit produce unusual conditions with respect to CURRENT STRENGTH AND DIRECTION. In the load circuit, the current varies, but it is always in the same direction. In the generator-battery circuit, however, current strength and direction are determined by the voltage conditions present at a particular instant. The series of circuit diagrams, shown in figures 58–65, illustrate all possible conditions that occur in load and generator-battery circuits.

POSSIBLE CONDITIONS

The diagrams for load and generator-battery circuits follow a definite sequence. The first circuit illustrates the condition that exists when the generator is in the circuit, but is not rotating. The next five show the generator COMING UP TO SPEED and increasing its voltage. The current in various parts of the circuit changes in magnitude and direction depending on the variations in generator voltage.

In figure 58 the generator IS NOT rotating. The generator voltage is ZERO. The line voltage EQUALS the battery terminal voltage. The battery

supplies current to the load and generator. The heavy current to the generator serves no purpose. In fact, it will result in serious damage to the gen-

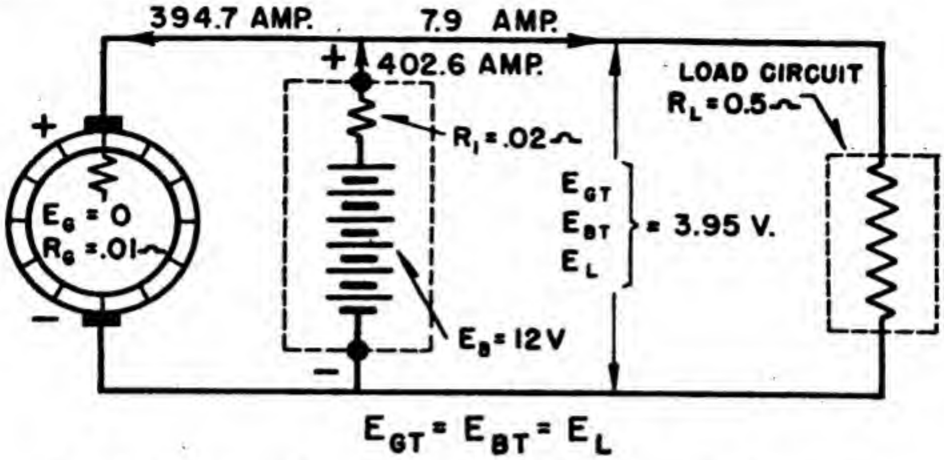


Figure 58.—Current strength and direction (generator not rotating).

erator. In an actual circuit, a CUT-OUT RELAY breaks the circuit whenever current flows in the wrong direction through the generator. The line voltage is only 3.95 volts because of the large IR drop in the battery and in the generator due to the heavy currents flowing through both units.

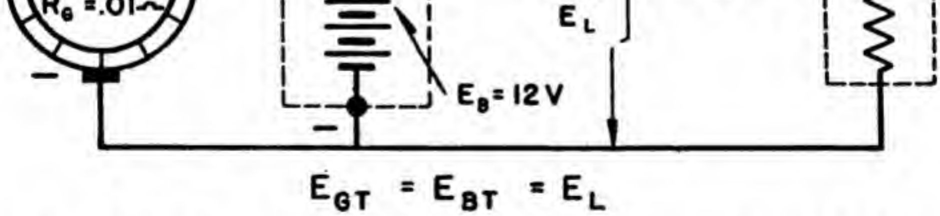


Figure 59.—Current strength and direction (generator rotating slowly).

The generator IS rotating in figure 59, but the induced emf produced is less than the terminal voltage of the battery. In this case, the line volt-

age is still EQUAL to the battery terminal voltage and the total current in the circuit is supplied by the battery. The discharge current to the generator, however, is much less. Consequently, the voltage drop within the battery is less. The line voltage has increased to 11.18 volts. This is nearer a normal condition of operation for devices in the load circuit, because these devices are designed for operation at 12 volts.

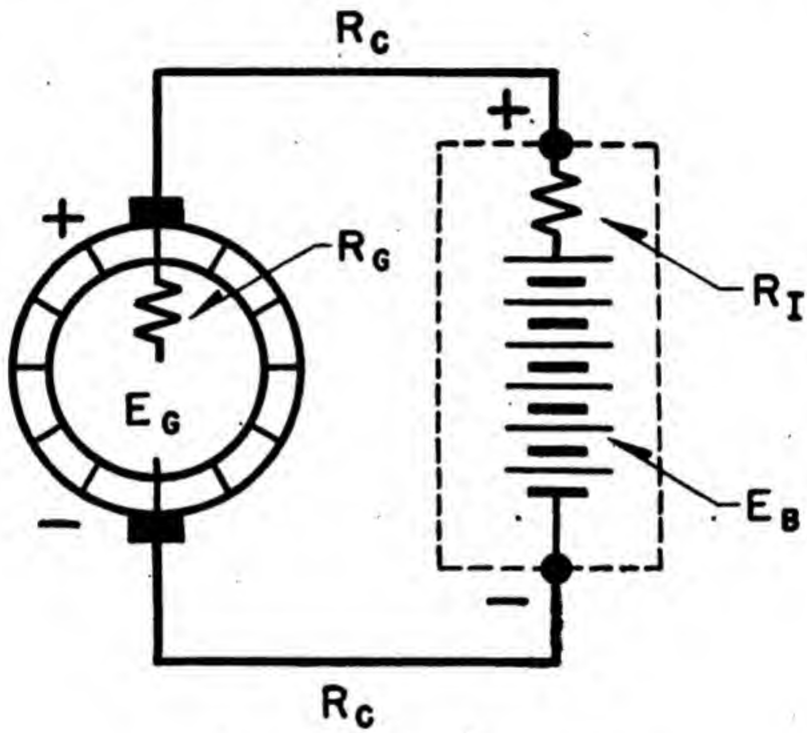


Figure 60.—Charging current.

The current in the battery and generator part of the circuit shown in figure 60 is determined by the TOTAL RESISTANCE of the circuit and the VOLTAGE acting on the circuit. Two voltages act on this circuit—the induced generator voltage and the battery electromotive force. THESE VOLTAGES OPPOSE EACH OTHER. The difference between the two voltages forces current through the circuit.

Because of the relatively low resistance of this part of the circuit, a very small difference between the two voltages will cause large currents to flow in this part of the circuit.

The CURRENT in the circuit represented in figure 60 CAN FLOW IN EITHER OF TWO DIRECTIONS. If the generator voltage is HIGHER than the battery voltage, the current becomes a charging current supplied by the generator. If the generator voltage is LOWER than the battery voltage, the current reverses in direction. This is a discharge-current supplied by the battery.

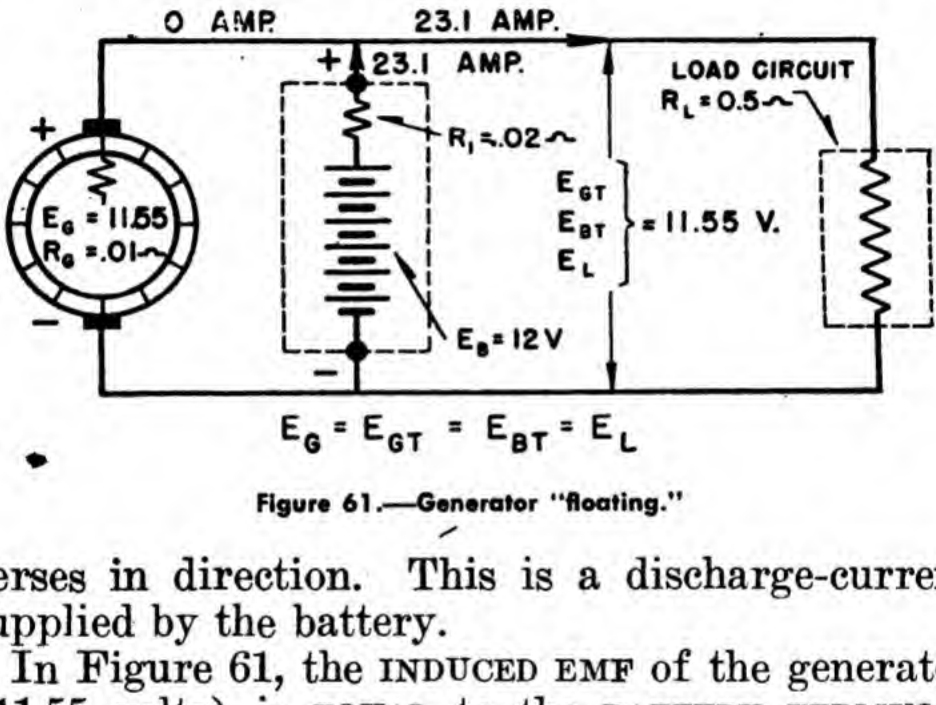


Figure 61.—Generator "floating."

In Figure 61, the INDUCED EMF of the generator (11.55 volts) is EQUAL to the BATTERY TERMINAL VOLTAGE. The battery supplies the total load current, no part of which goes to the generator. The generator neither receives nor delivers current—it FLOATS on the line.

In figure 62 the LOAD CURRENT is supplied by BOTH generator and battery. The portion of the total current, supplied by each unit, is determined by internal resistance. The BATTERY TERMINAL VOLTAGE, GENERATOR TERMINAL VOLTAGE, and LINE VOLTAGE are all EQUAL.

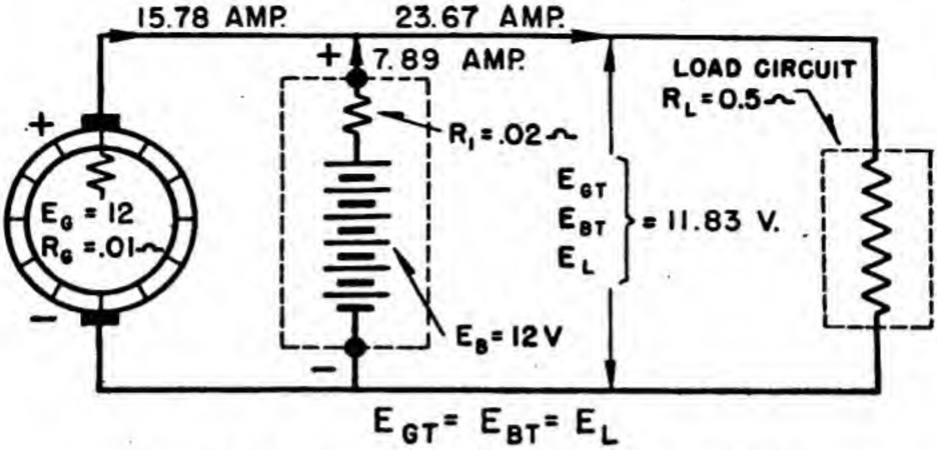


Figure 62.—Generator and battery supplying load.

The GENERATOR TERMINAL VOLTAGE is EQUAL to the BATTERY ELECTROMOTIVE FORCE in figure 63. The generator supplies all the load current and the battery floats on the line. The battery terminal voltage is equal to the battery electromotive force, because there is no voltage drop across the internal resistance. The GENERATOR TERMINAL VOLTAGE, BATTERY EMF, and LINE VOLTAGE are EQUAL.

In figure 64 the GENERATOR TERMINAL VOLTAGE is GREATER than the BATTERY ELECTROMOTIVE FORCE. A voltage difference in favor of the generator exists. Both the charging current and the load current are supplied by the generator. When an airplane is in normal flight, a similar condition exists in the

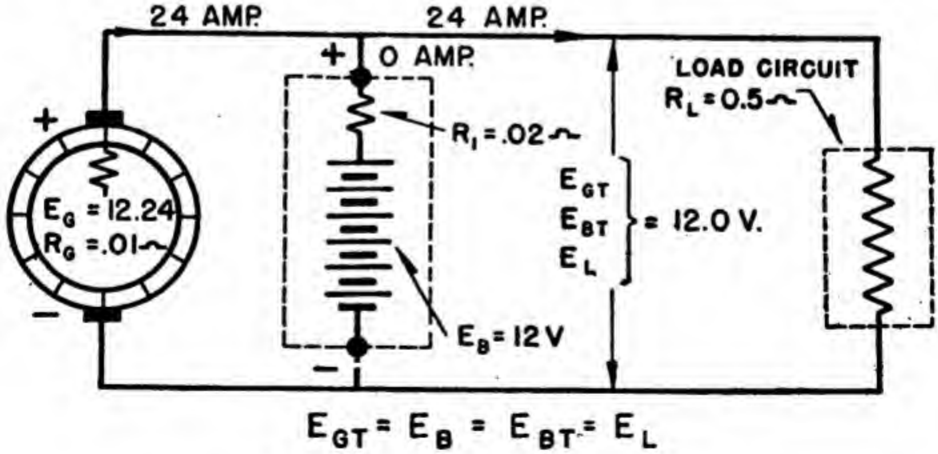


Figure 63.—Battery "floating."

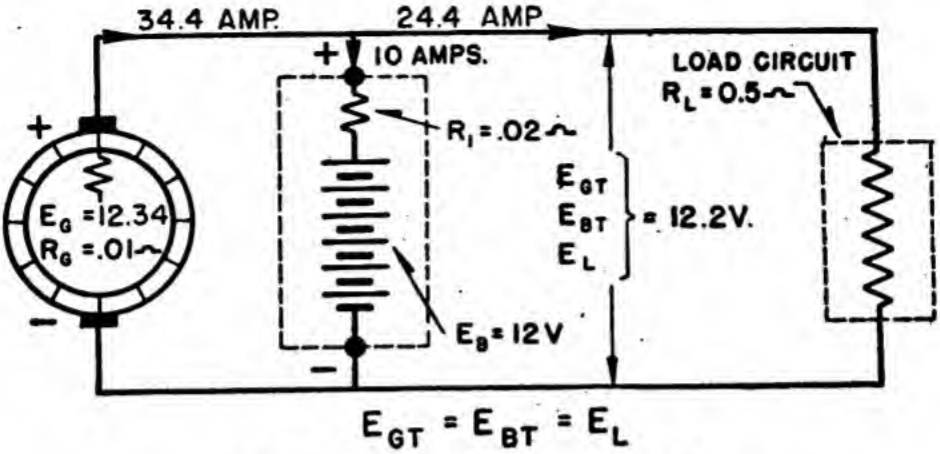


Figure 64.—Battery being charged.

charging circuit. Under normal operating conditions, all current in the electrical system is supplied by the generator.

As the engine drives the generator to higher speeds, the generator voltage continues to rise. Figure 65 shows the induced voltage in the generator is 16 volts. The line voltage applied to the load is 14.47 volts. As this is a 12-volt system, a line voltage of 14.47 is HAZARDOUS for the lights and instruments in the load circuit. Furthermore, the charging current through the battery is 123.5 amperes and the generator supplies a total current of 152.44 amperes. This EXCESSIVE CURRENT will burn out the generator armature.

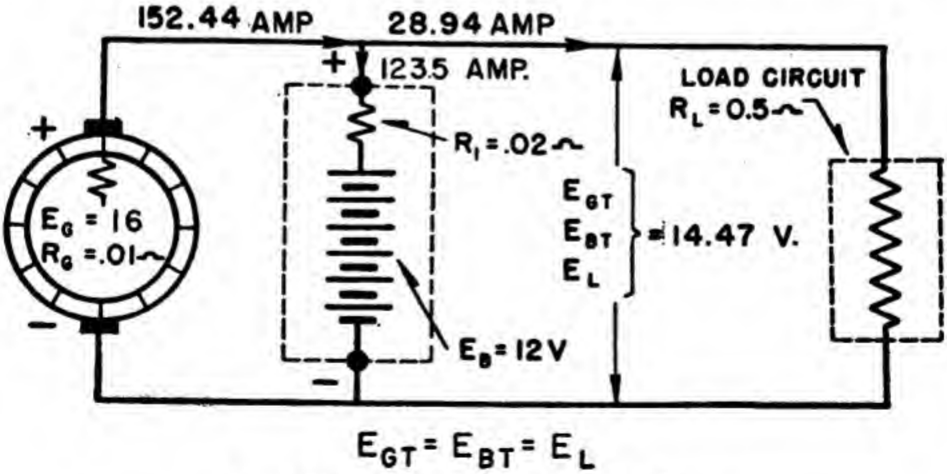


Figure 65.—Excessive generator voltage.

If the generator voltage goes higher, the condition becomes more dangerous. The lights and generator armature are certain to be damaged unless the voltage is kept below a given maximum value. THEREFORE, IN ALL ELECTRICAL SYSTEMS OF THIS GENERAL TYPE YOU MUST USE SOME FORM OF VOLTAGE REGULATION.

NEED FOR REGULATORS

If an efficient voltage regulator is used, the electrical devices are protected from the effects of overvoltage. Under normal operating conditions the generator also is protected. Excessive current resulting from short circuits or overloading of the load circuit, however, may damage the generator.

The load current supplied by the generator is dependent on the generator terminal voltage and the total resistance of the load. Normally, the generator voltage is fixed by the action of the regulator—the total resistance in the load circuit is determined by the number of devices placed in operation. As the number of devices in the load is fixed, the total current supplied by the generator should not exceed a definite value. This DOES NOT take into account circuit faults. A short circuit or a defective battery would alter the situation.

Overloading and short circuits lower the total circuit resistance and cause excessive current drain from the generator. The excessive current could easily damage the generator armature. A voltage regulator cannot control this situation because the trouble is primarily a variation in load resistance. A fuse or circuit breaker inserted in the generator circuit limits the maximum current supplied by the generator. In some power supply systems current regulators are used to limit the total current.

A careful study of the eight circuit diagrams reveals some SERIOUS DEFECTS. The battery discharges heavily through the generator and the line voltage is very low when the generator is not rotating. This action would completely discharge the battery in a short period of time and also burn out the generator armature. Some means, therefore, must be provided for disconnecting the generator from the system whenever its voltage is lower than that of the battery.

The second circuit diagram shows that the current in the circuit loop—formed by the battery and generator—is sensitive to generator voltage change. The discharge current through the generator is relatively small because the generator voltage opposes the battery voltage. The voltage difference between the two units is effective in sending current around the circuit. A similar condition exists whenever the engine is stopped and the generator voltage becomes lower than the battery voltage. The battery discharges momentarily into the generator, whereupon the cutout relay functions to break the connection.

Figures 59, 61, 62, 63, 64, and 65 illustrate conditions that are found in actual practice. They indicate wide variation in the charging current but relatively small changes in load current and load voltage. Figures 58 and 59 show the need for preventing the battery from discharging through the generator. This is accomplished by means of the REVERSE CURRENT RELAY. Figure 65 clearly indicates the need for some device that will place a CEILING on the generator voltage. This is the function of the voltage regulator.

CHAPTER 8

REVERSE CURRENT RELAYS

SIMPLE RELAY

Suppose you have to pump water up through a pipe and into an elevated storage tank. The supply in the tank may be drawn off as desired for consumption. But a mechanical breakdown causes the pump to stop working. All the water in the tank will flow back through the tank unless something is done to prevent it. A CHECK VALVE, which will remain open and let the water flow only in an upward direction, is the answer. When the water starts to flow downward, the valve closes and prevents the water from entering the pump. Meanwhile, water may still be procured from the storage tank. The REVERSE CURRENT RELAY serves the same purpose in a circuit that the CHECK VALVE does in a water system.

The problem is to prevent the battery from discharging through the generator, whenever the battery voltage is higher than the generator voltage. This requires the use of a CUT-OUT RELAY CIRCUIT.

A simple relay has been placed in the generator circuit in figure 66. Normally the contact points

of the relay are held open by a spring. When the engine begins to rotate, the generator voltage builds up and forces current through the relay circuit—the only path for current at the time. The spring tension is adjusted so that the contacts will close when the voltage of the generator reaches 13.5 volts.

Closely the relay-contact places the battery IN PARALLEL with the generator. This causes a charging current to flow through the battery. As the generator voltage continues to increase, the battery-charging rate also increases. Because the current to the relay also increases, the contacts will be held tighter.

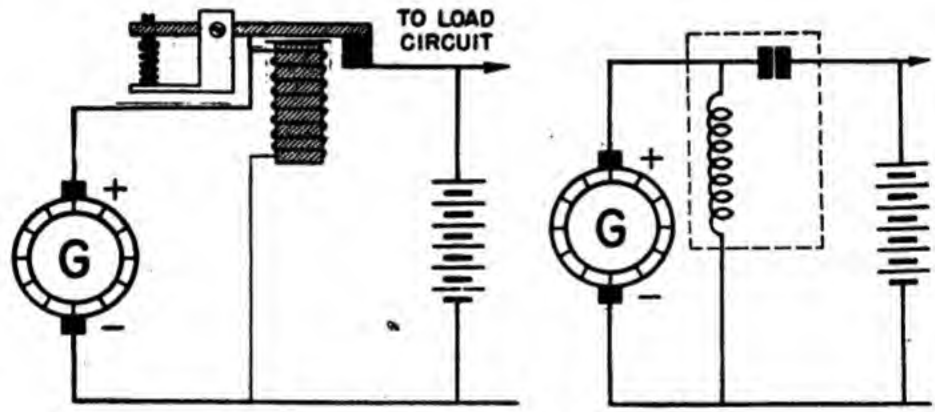


Figure 66.—Simple cut-out relay.

If the engine were allowed to idle or to stop, the generator speed would decrease, and the generator voltage would fall below 13.5 volts. The battery would try to send current in the opposite direction through the generator. The relay would prevent this because the contacts open as soon as the voltage falls below 13.5 volts. A simple means of disconnecting the generator from the battery!! THEORETICALLY the relay SHOULD operate as described. But it doesn't! Certain peculiarities of an iron-core circuit must be considered. The foregoing example was illustrative. An analysis

of its failure to operate properly will clarify the reverse-current cut-out relay, WHICH DOES WORK.

The following will explain why the relay, diagrammed in figure 66, cannot function properly. In figure 67 the same relay is shown connected to a battery and a potentiometer, which makes it possible to vary the voltage applied to the relay. If the voltage is INCREASED GRADUALLY, the relay

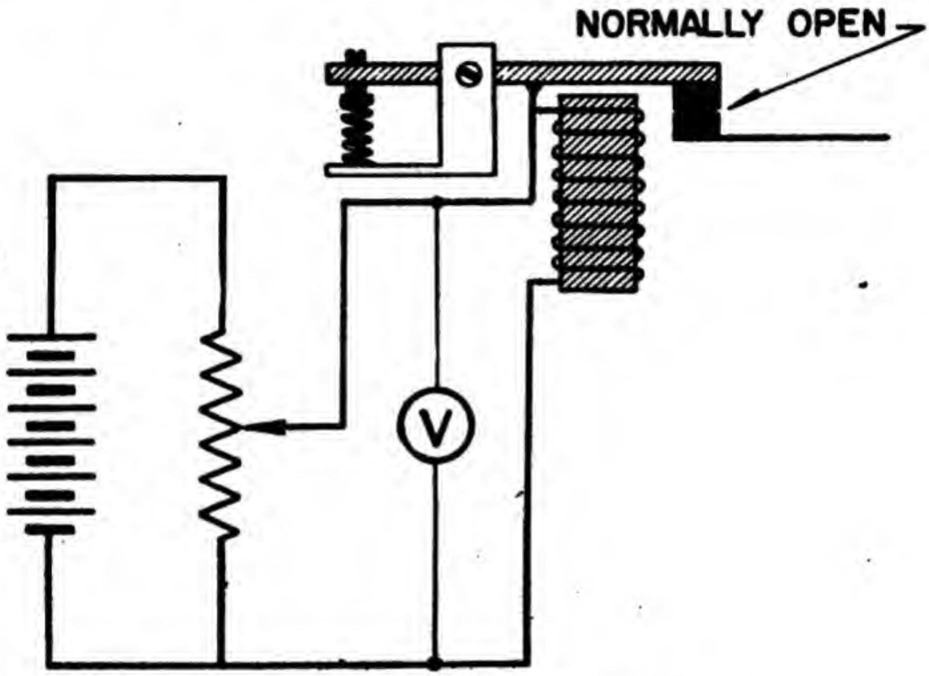


Figure 67.—Experimental relay circuit.

closes at 13.5 volts. If the voltage is increased further, the relay contacts remain closed. Now suppose the voltage applied to the relay coil is reduced gradually. You would expect that when it reached 13.5 volts, the contacts would open. But they won't.

The reason for the failure of the contacts to open may be explained by examining figure 68. The graph indicates the relationship between applied voltage and magnetic strength of a soft-iron core such as that used in the relay. As the voltage is increased, the magnetic strength increases

along the rising curve, *ABC*. At *B* (13.5 volts) the relay contacts close. If the voltage is increased to 16 volts, the magnetic strength is represented at *C*.

If the voltage is decreased, the magnetic strength does not decrease back along line *ABC*. Instead, it decreases along the line *CDEF*. At 13.5 volts the magnetic strength has a value shown by *D*, which is higher than the strength required to close the contacts (represented by *B*). To open the contacts, the magnetic strength must be re-

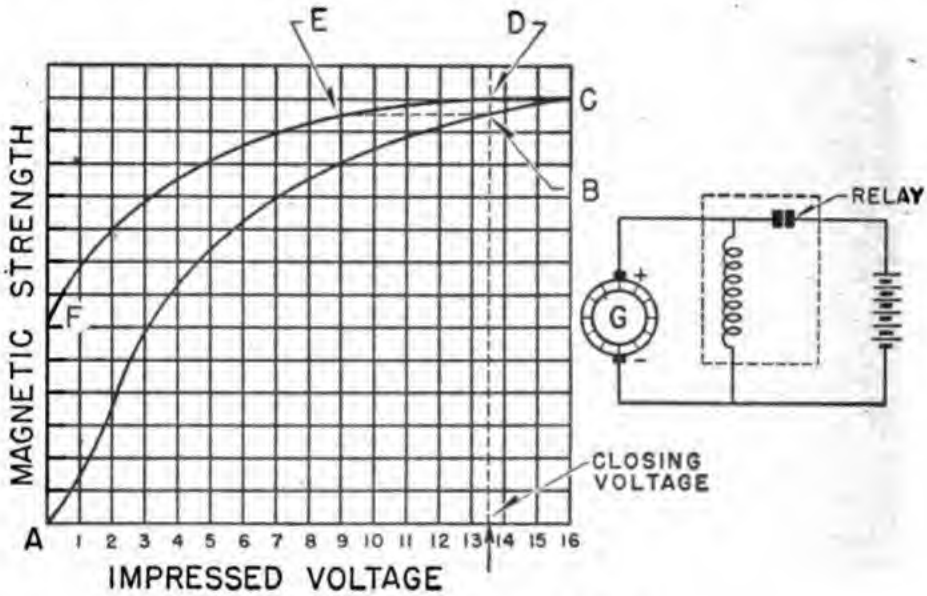


Figure 68.—Hysteresis effect.

duced until it corresponds with the *B* level. In order to obtain this value, it is necessary to reduce the voltage to 9 volts. The magnetic strength at this voltage is represented by *E* which has the same value as *B*. With a decrease in voltage, the decrease in magnetic strength lags behind the voltage. This magnetic effect is known as HYSTERESIS.

The schematic in figure 68 shows why the simple relay is inadequate. If the relay-points are to open, the voltage acting on the relay must be re-

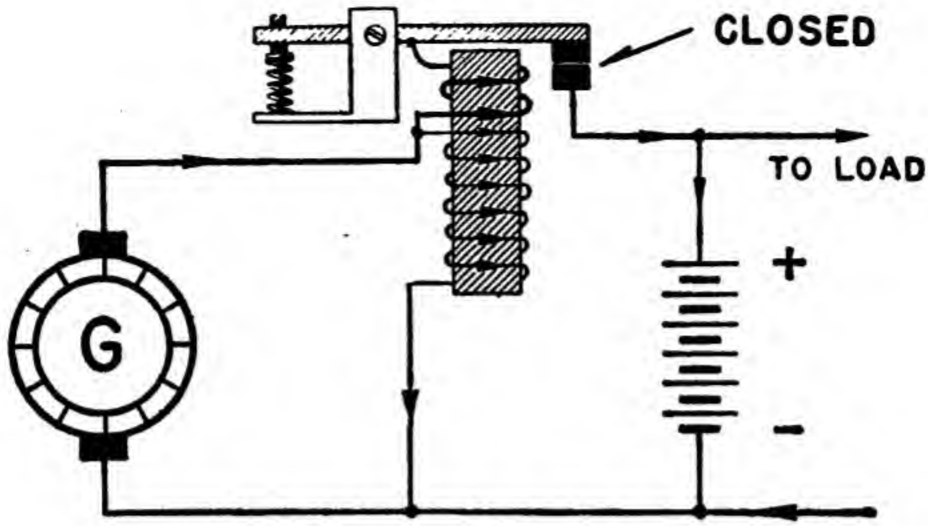
duced to 9 volts. This is not possible. When the contacts are closed, both battery and generator are IN PARALLEL with the relay coil. Hence, even if the generator voltage drops, the battery still impresses 12 volts across the relay and keeps the current flowing in the relay coil. The points cannot open. The battery continues to discharge into the relay and generator. But there is a relay which will function—the reverse current cut-out relay.

MAKING IT WORK

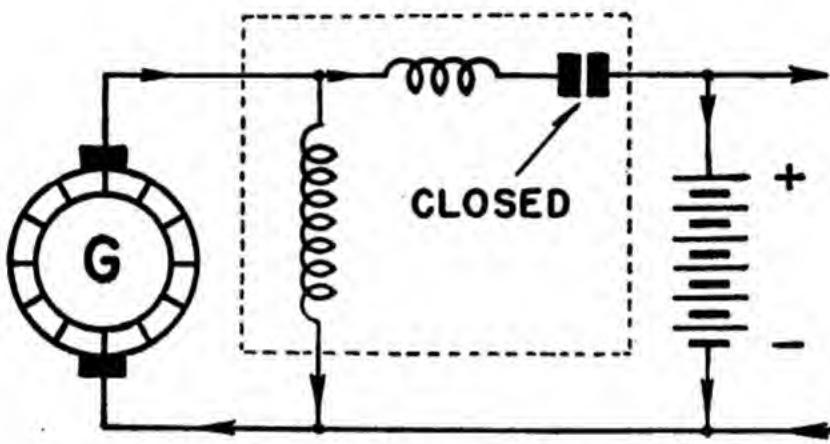
In figure 69, the reverse current cut-out relay is connected in the generator battery circuit. The relay has two windings on a soft-iron core. The shunt winding has many turns of wire connected directly across the line. It is sometimes called the VOLTAGE COIL. The other coil is known as the SERIES or REVERSE CURRENT COIL. The series coil has several turns of relatively heavy wire. The series coil overcomes the disadvantages of the simple relay discussed in the preceding paragraphs.

The contact points normally are held open by an adjustable spring disconnecting the generator from the line. When the engine begins to rotate, the generator voltage increases. This increases the current through the shunt coil of the relay, which is always across the generator terminals. The current in the shunt coil is proportional to the generator voltage. Tension of the contact spring is adjusted so that the relay contacts close when the generator voltage exceeds the battery voltage.

Closing the contacts connects the generator to the line. THE GENERATOR CONTINUES TO SEND CURRENT THROUGH THE SHUNT COIL. In addition it also furnishes load current which passes through the series coil, the contact points, and the load circuit.



(A) CHARGE



(B) CHARGE

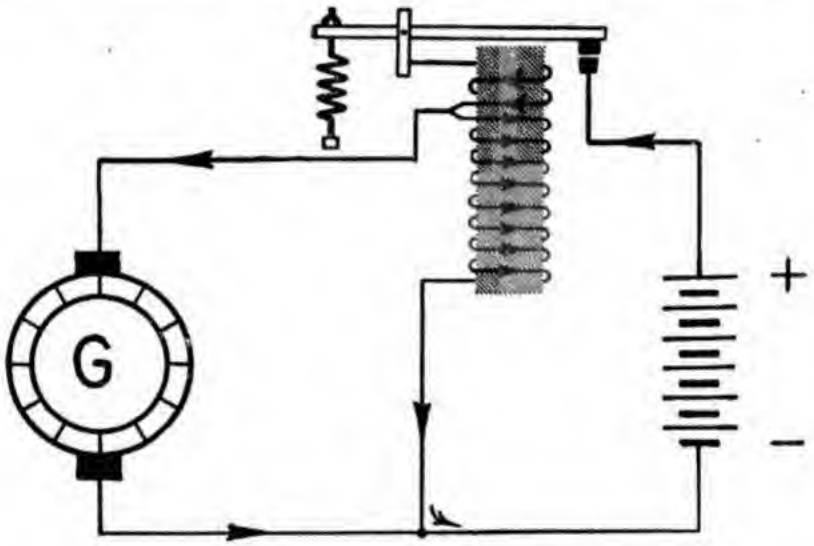
Figure 69.—Reverse current cut-out relay (charge).

The currents in the shunt and series coils flow in a direction so that the coils assist each other in strongly magnetizing the core. The contacts will remain closed as long as current flows to the load circuit.

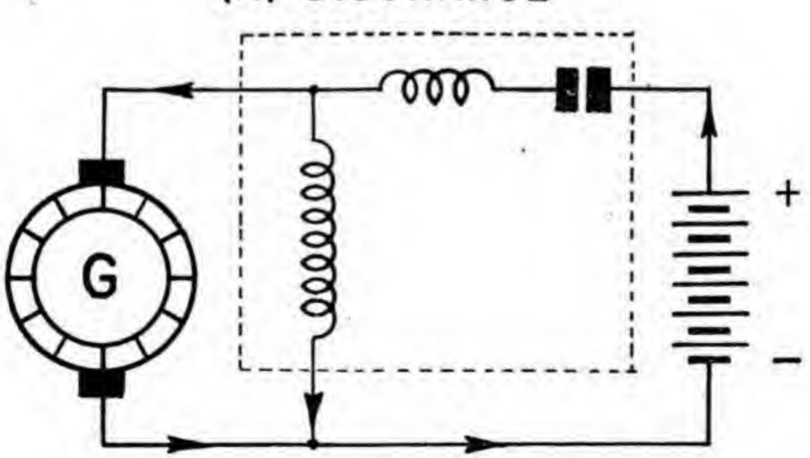
When the engine stops or idles, the generator voltage decreases. When the point is reached at which the battery voltage is greater than the generator voltage, the BATTERY MOMENTARILY DISCHARGES BACK THROUGH THE GENERATOR. This discharge-current flows through the series coil in

the opposite direction as shown in figure 70. The current in the shunt coil continues in the original direction. The series coil now OPPOSES the shunt coil and CANCELS the magnetism in the core. This action permits the spring to separate the contacts, thus disconnecting the generator from the circuit.

You may have been told that the relay regulates the charging rate of a battery. Don't believe it. It does nothing of the sort! The relay has NO EFFECT on either the LOAD CURRENT or the BATTERY CHARGING RATE. It is an automatic switch that



(A) DISCHARGE



(B) DISCHARGE

Figure 70.—Reverse current cut-out relay (discharge).

prevent the battery from discharging through the generator whenever the engine idles or stops rotating.

Occasionally, a generator loses its residual magnetism. When this occurs, it fails to generate voltage when rotated. There are several ways of RESTORING the residual magnetism. One quick method is to close the contacts of the cut-out relay by hand. Under certain conditions, however, this procedure reverses the magnetic field of the generator. When such reversal occurs, the electrical polarity of the brushes also reverse.

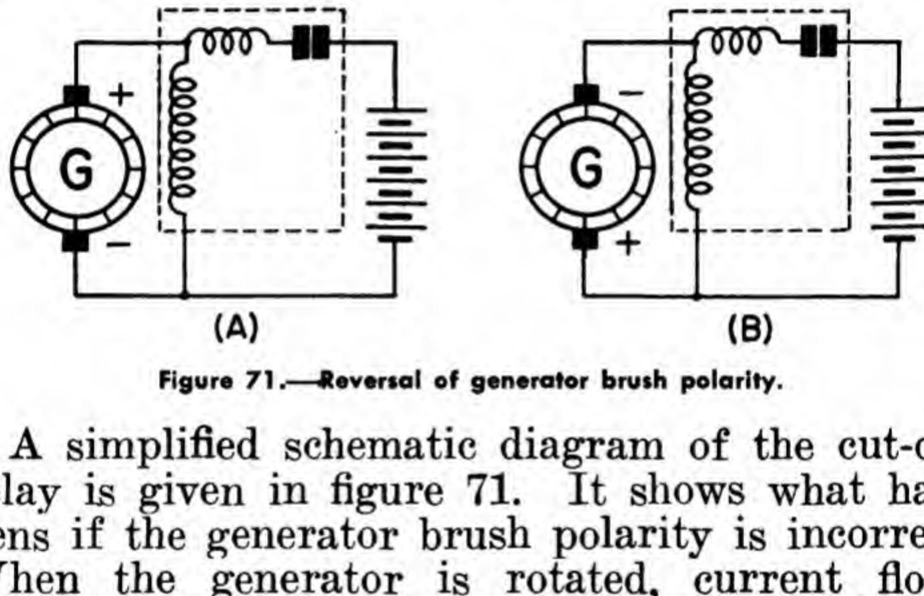


Figure 71.—Reversal of generator brush polarity.

A simplified schematic diagram of the cut-out relay is given in figure 71. It shows what happens if the generator brush polarity is incorrect. When the generator is rotated, current flows through the shunt coil of the cut-out relay in the opposite direction. Because the core is magnetized by current in either direction, the relay closes at the operating voltage determined by spring tension.

Under normal conditions, closing the contact points connects the positive terminal of the generator and the positive terminal of the battery. Under conditions of incorrect polarity, the positive terminal of the generator and the negative terminal of the battery will be connected. The battery and generator are then in series across

both the contact points and the series coil of the relay. The extremely heavy current really amounts to a short circuit on both generator and battery. The heat generated is USUALLY sufficient to melt the contact points and ruin the wiring.

Usually, fuses are placed in the circuit to guard against this contingency. Some circuit arrangements prevent the relay contacts from closing IF the generator polarity is incorrect. The ORDINARY REVERSE CURRENT RELAY WITH A RECTIFIER UNIT IN SERIES WITH THE SHUNT COIL meets these requirements.

COPPER-OXIDE RECTIFIER

Figure 72 is a simplified schematic diagram of the G. E. reverse current relay unit. Except for

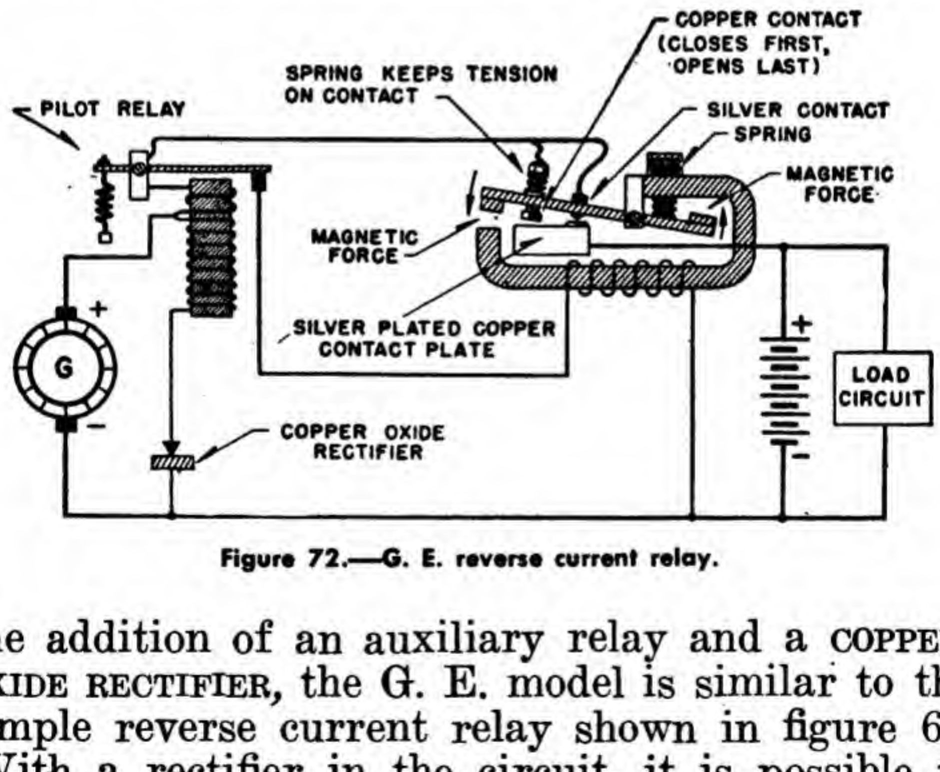


Figure 72.—G. E. reverse current relay.

the addition of an auxiliary relay and a COPPER-OXIDE RECTIFIER, the G. E. model is similar to the simple reverse current relay shown in figure 69. With a rectifier in the circuit, it is possible to obtain current flow IN ONE DIRECTION ONLY. Thus, the relay closes if the generator brush polarity is correct. If the generator brush polarity reverses,

the relay contacts CANNOT CLOSE because energizing current cannot flow in the opposite direction.

The G. E. unit was designed for operation with large load currents. In order to conduct the current, an ADDITIONAL MAIN LINE RELAY is used. The relay consists of a single coil on an iron core and a set of main contacts. The contacts are made of silver and are about ½ inch in diameter.

Silver is an excellent conductor of electricity. It is, however, a comparatively soft metal, and is easily pitted by arcs that form when the contacts open or close. In order to prevent arcing at the silver contacts, the contact arm is provided with a set of copper contacts in shunt with the silver contacts. The construction of the relay is such that the copper contacts close first, momentarily taking the load current. The silver contacts, in closing an instant later, carry practically the full load current. Whenever the relay points open, the silver contacts break first and the main load current is diverted momentarily to the copper contacts. An instant later the copper contacts break and ANY ARCING that occurs is ALWAYS at the copper contacts.

The copper-oxide rectifier is not a perfect rectifier. But it offers high resistance to the current flow in the opposite direction. (In this particular relay the maximum allowable current in the reverse direction is approximately 50 milliamperes at 28.5 volts. The minimum current in the correct direction should be about 80 milliamperes at the same voltage.)

The operation of the complete unit is similar to that of a conventional reverse current relay. Normally the "pilot" relay contact points are open. As the generator voltage rises, the current through the shunt coil and copper-oxide rectifier

increases. At a predetermined voltage, the current becomes sufficient to magnetize the core and close the contact points. This energizes the solenoid of the main line relay by placing that relay across the line voltage. The relay, in turn, closes the main line contacts. The main load current immediately passes through the copper contacts. A moment later it passes through the silver contacts and shunts the copper contacts.

When the generator voltage decreases to a value below the battery voltage, a reserve current flows through the series winding of the pilot relay. The action opens the contacts and breaks the circuit to the main line relay. The contact arm of the main relay moves upward, drawing the silver contacts apart first. The full load current then passes through the copper contacts prior to the break. Thus, it is seen that the silver contacts break only a fraction of the total load current. The copper contacts break the full load current.

The diagram in figure 72 shows the double contacts on the main relay in an arrangement which differs somewhat in construction from the actual unit. The PRINCIPLE OF OPERATION, however, is the same.

NEW TYPE RELAY

The purpose of the copper-oxide rectifier is to prevent the reverse current cut-out relay from closing in the event the generator voltage is of reversed polarity. A NEWER TYPE RELAY (G. E. 3GTR72A1A) employs the rectifier for a different purpose and has another means of preventing the relay contacts from closing if the generator polarity is reversed. This type relay insures opening the relay contacts even if a high reverse current flows to the generator.

The reverse current relay, figure 73, consists essentially of two parts—

A CURRENT-CARRYING MAIN CONTACTOR, connected in series with the generator which connects it to the main bus, and

A POLARIZED, OR PILOT, RELAY in which the action is dependent upon correct generator voltage and excessive reverse current.

The potential coil of the polarized relay is connected in series with the single disk copper-oxide rectifier and a 250-ohm resistance across the output of the generator. The magnetic pull of the coil *C*-1 (one leg of the U-shaped magnetic core) is proportional to the voltage of the generator, but it opposes the action of the spring. By adjusting the spring tension, the voltage can be regulated to a point at which the contacts *PC* will close. When these contacts close, coil *C*–2 is energized and closes the main contacts *MC*. This connects the generator to the main bus.

The relay is provided with a reverse current coil *C*–3 that always opens the contacts when a current of 8 to 20 amperes flows in the reverse direction at a line potential of 27.5 volts. This coil of two turns is wound on the other leg of the U-SHAPED MAGNETIC CORE.

When the current is flowing in the correct direction, its magnetic flux aids the flux of the potential coil. This prevents the relay from opening in case the generator voltage drops below normal closing voltage because of the increased load. If a reverse current flows, however, the flux of the current coil opposes that of the potential coil and allows the spring to open the contacts.

When the current reverses quickly to a high value, the reversal sometimes occurs so rapidly that the spring does not have time to act. In

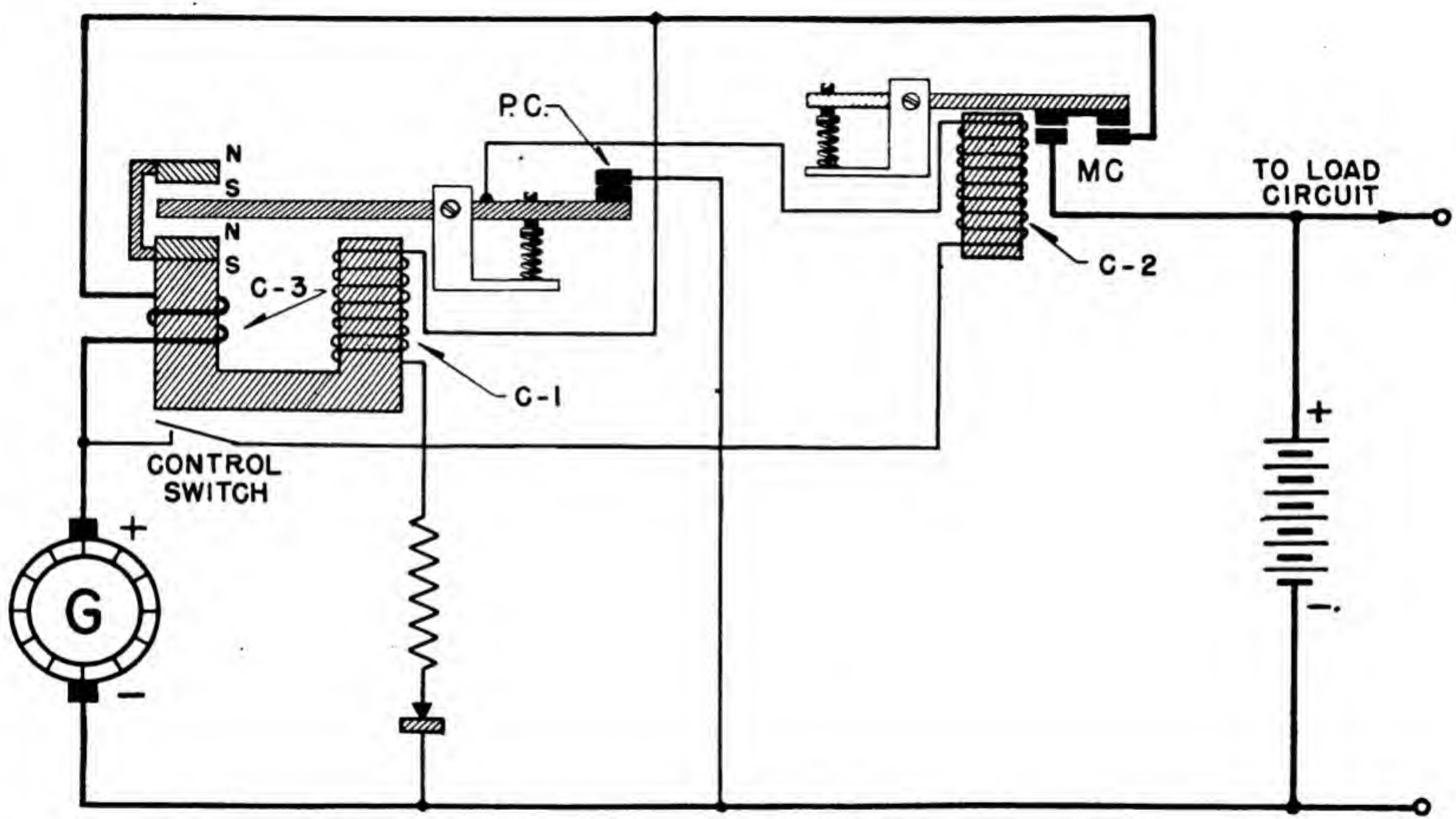


Figure 73.—Schematic diagram of G. E. 3GTR72A1(A) reverse current relay.

other words, the flux of the current coil is sufficient to overcome the potential coil flux and to hold the relay closed. Two small permanent magnets, mounted on the core above the current coil, overcome this fault. The magnets, made of alloy, possess the property of high retentivity. Their purpose is twofold—

First, they insure opening of the contacts when high reverse current flows.

Second, they prevent operation of the relay if the generator polarity is reversed. Originally, it was the function of the rectifier to prevent operation in case of polarity reversal. At the present time the rectifier is retained in the circuit because the resistance of the nonmetallic conductor decreases as the temperature rises and the resistance of the metallic potential coil increases as the temperature rises. A 250-ohm resistor, placed in the circuit, limits the current to an amount which provides the desired ampere turns in the potential coil.

Figure 74*A* shows the magnetic path when current flows in the correct direction through the current coil. The potential-coil flux and current-coil flux are in the same direction in the U-shaped core. When an extremely high reverse current flows through the current coil, the flux produced overcomes the potential-coil flux. The U-shaped magnets are polarized in the opposite-to-normal direction, and the magnetic path shown in figure 74*B* is the result. The polarity of the lower permanent magnet opposes the reverse-current flux. The upper permanent magnet assists the reverse-current flux to pass through the upper magnet and the permanent magnet yoke. The upper magnet attracts the armature and opens the relay contacts.

The same condition would exist if the generator had reverse polarity. The flux from the potential coil, however, would be reversed and would not allow the relay to close.

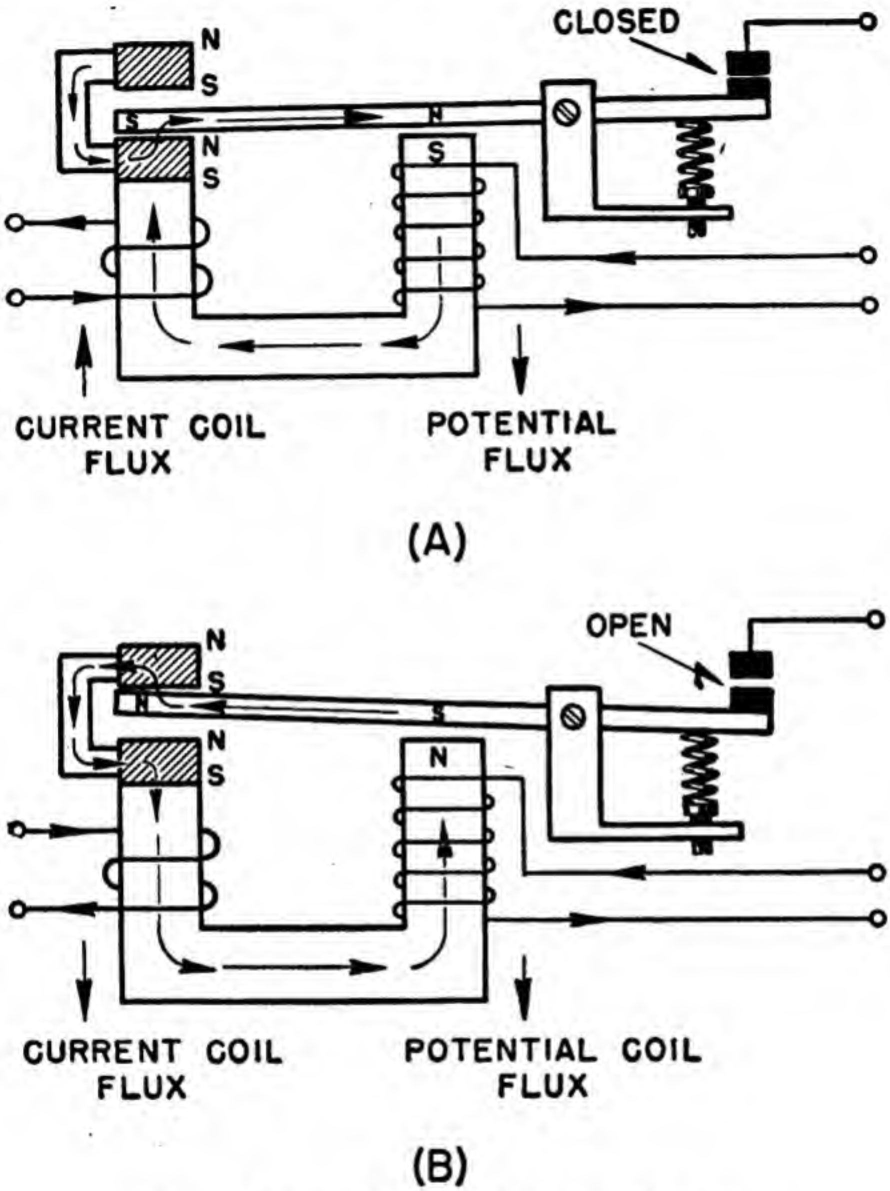


Figure 74.—Flux condition in polarized relay.

CHAPTER 9

VOLTAGE REGULATION

WHAT IT DOES

You're rolling along a nice level stretch of highway with the foot throttle well down toward the floor. The motor is purring and the speed is definitely pre-war. But as you start to climb a long hill you notice a perceptible slowing up of your speed even though you depress the old throttle more and more. That is because hill climbing places a new load on the motor—and the steeper the hill the greater the load. The voltage regulator adds a similar load to the generator voltage at high speeds of the driving engine—and so reduces the induced emf.

A CONSTANT LINE VOLTAGE must be maintained in a simple power supply system. But the voltage of any generator is dependent on the speed of rotation. Thus, if the generator operates IN PARALLEL with the battery, the line voltage produced by the combined units varies with the generator speed.

The solution would be simple if the generator could be made to operate at a constant speed. A partial solution has been the use of a slipping clutch between the generator drive shaft and the engine. The clutch is so designed that it starts

to SLIP at a certain engine speed, and will not drive the generator at a greater speed even though the speed of the engine is increased.

The slipping clutch arrangement is still used in certain types of naval aircraft. It is being replaced, however, by direct drive units. In every case, it is used in conjunction with a voltage regulator, and it serves to reduce the work of the regulator.

If the generator is energized by direct drive from the engine—as is now the general condition—all attempts to maintain a constant generator voltage are concerned with the INTERNAL FEATURES OF THE GENERATOR.

The induced voltage of a generator depends on two factors. One of these is the NUMBER OF CONDUCTORS in the armature. This is fixed when the armature is designed by the manufacturer. For practical reasons the number of conductors cannot be changed. The second factor is the RATE OF CUTTING MAGNETIC FLUX, which depends on the speed of the armature. The engine drives the armature—nothing can be done about controlling its speed. The factor that CAN be regulated is THE AMOUNT OF FLUX.

In all aircraft generators, magnetic flux is supplied by an electromagnetic field. The amount of flux produced is a function of the field current. In turn the current is determined by the voltage impressed on the field and the resistance of the field. By controlling the field resistance, it is possible to reduce or increase the field strength. For a given speed the decreasing or increasing the field strength increases or decreases the induced voltage produced in the generator armature. THE VARIATION OF GENERATOR VOLTAGE BY CONTROL OF FIELD RESISTANCE IS THE BASIS OF NEARLY ALL VOLTAGE REGULATORS.

Figure 75 illustrates the SIMPLEST FORM OF VOLTAGE REGULATOR. A variable regulator resistor has been placed IN SERIES WITH THE FIELD WINDING of the generator. At a given speed the generator terminal voltage has a definite value. If the speed is increased, the generator terminal voltage increases. At an increased speed the generator voltage can be reduced to its original value by increasing the field resistance which reduces the field current, field flux, and induced emf. Thus, the generator can be kept at a constant voltage by variation of the field regulator resistor.

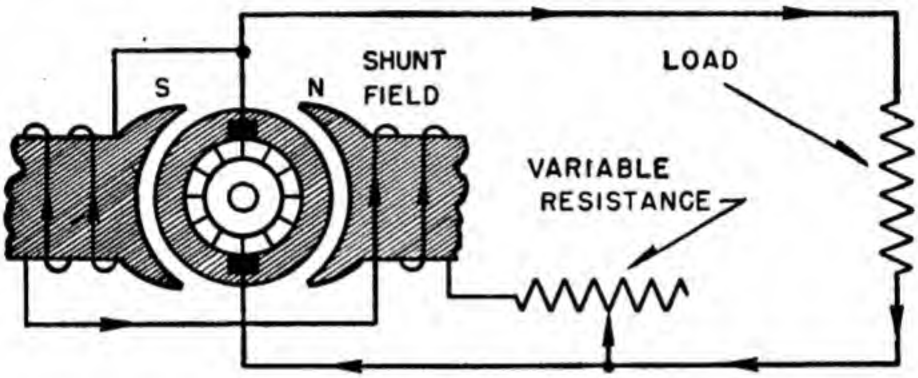


Figure 75.—Voltage regulator.

In figure 75 the field resistance is controlled MANUALLY. ACTUALLY, in a voltage regulator the control action would be AUTOMATIC. Various methods are used to secure automatic action. The principle of operation in all cases, however, is a VARIATION OF FIELD CURRENT THROUGH CHANGE IN FIELD RESISTANCE.

VIBRATION FOR REGULATION

In the circuit diagram shown in figure 76 a fixed resistor has been placed in the field circuit. The regulating resistor is bridged by two contact points. When the points are closed, the regulating resistor is short circuited and the ONLY RESISTANCE present is in the FIELD WINDINGS. Under

this condition the generator will develop maximum voltage for a given speed. If the contact points are opened, the short circuit is removed and the RESISTANCE of the field circuit becomes that of the windings PLUS that of the regulating resistor. Under this condition the field current is reduced and the generator voltage also decreases.

If the contact points are made to VIBRATE with great rapidity, the field current is alternately increased and decreased at the same rate. The

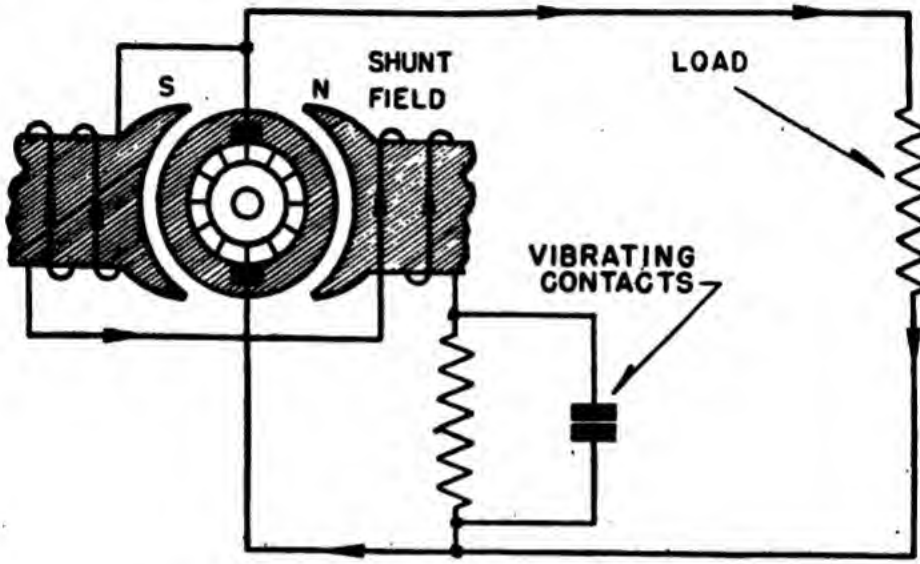


Figure 76.—Vibrating contact regulator.

induced voltage of the generator is correspondingly increased and decreased. Hence, with this arrangement the instantaneous induced emf of the generator is alternately higher and lower than the required voltage. BUT A CONSTANT VOLTAGE IS REQUIRED. And by controlling the rate of vibration of the contacts, the AVERAGE voltage IS held substantially constant. All vibrating type voltage regulators operate on this principle.

For automatic operation, the contact points must be controlled by a vibrating mechanism. The mechanism must be controlled by the line voltage variation which it seeks to eliminate.

Figure 77 is a schematic diagram of a typical vibrating voltage regulator. The regulator consists of a single winding on a soft-iron core, and a vibrating armature fitted with contact points. The regulator coil winding (shunt coil) is connected DIRECTLY across the generator terminals. The contacts are bridged across a regulator resistor in the field circuit of the generator.

Normally the contact points are held closed by the action of an adjustable spring. When the generator is rotating at a speed such that the line

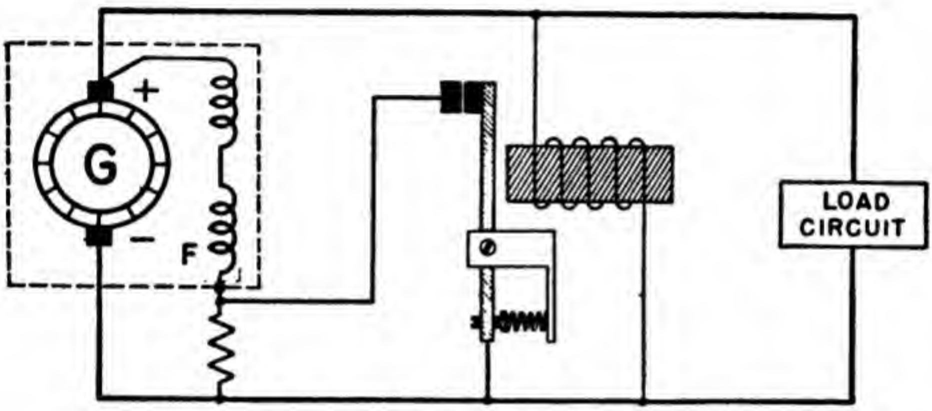


Figure 77.—Vibrating voltage regulator.

voltage is normal or below, the contacts remain closed. Under this condition the regulator resistor in the field circuit is short-circuited by the points, and a normal field current flows. Current also flows through the shunt coil of the regulator. The strength of the current is proportional to the generator voltage. With normal voltage, the current is not strong enough to energize the core. Hence, the points STAY CLOSED.

If the generator voltage, because of increased speed, goes above the rated line voltage, the regulator begins to function. Current in the regulator coil is strong enough to energize the core and attract the armature. The action OPENS THE CONTACTS. When the points separate, the field circuit

resistance is increased by the amount of the regulating resistor bridged across the contacts. The increase in field resistance lowers the generator field current which, in turn, reduces the amount of magnetic flux in the field poles.

The armature conductors now have less flux to cut and the generator terminal voltage falls. The reduction in generator voltage reduces the current through the relay. Consequently, the points close and again short circuit the regulating resistor. The action increases the field current and the generator terminal voltage. Again the points open. The result of the cycle of operation is a HIGH-SPEED VIBRATION of the regulator armature.

The speed with which the regulator contacts vibrate affects the efficiency of the regulator. Two factors limit the rapidity of this action—the inertia (resistance to movement) of the contact arm and the speed with which magnetism is reduced in the core when the contacts open. To speed up the action of the contacts, vibrating voltage regulators often are provided with a second winding, which is used to demagnetize the core.

A voltage regulator which incorporates this demagnetizing winding is illustrated in figure 78. Normally, the contact points are held closed by an adjustable spring. In this position, BOTH the demagnetizing winding and the field regulating resistance are short-circuited by the closed contacts. When the line voltage is correct, the contacts remain closed and the only resistance in the field is that of the field windings. If the generator voltage rises above the normal rated voltage, the contact points open. The separation of the points places the regulating resistor and demagnetizing winding IN SERIES with the field circuit.

The increase in field resistance reduces the field current. This action LOWERS the generator terminal voltage. The reduced field current, however, passes through the demagnetizing winding. Its direction is such that it opposes the action of the regulator shunt winding. This produces a RAPID DEMAGNETIZATION of the core, and speeds up the rate of vibration of the regulator armature.

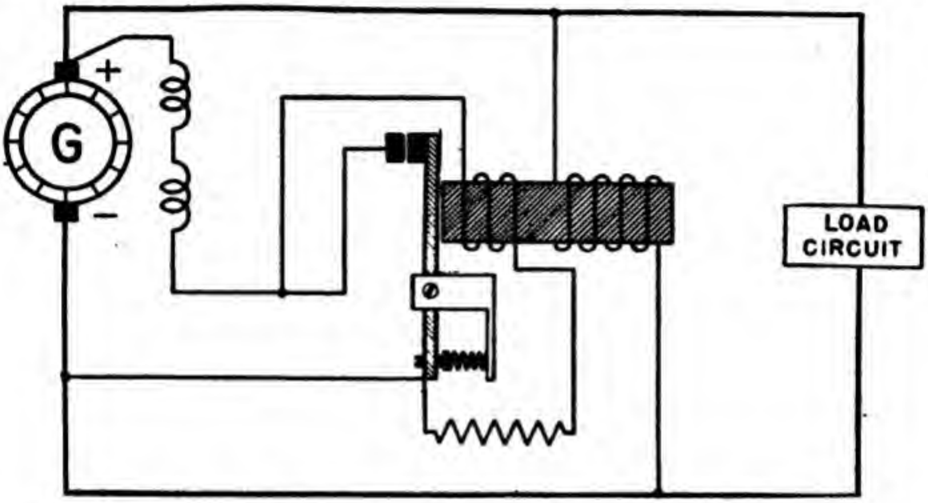


Figure 78.—Voltage regulator with demagnetizing winding.

An efficient voltage regulator PROTECTS the devices in the load circuit from damage by overvoltage. The regulator, however, DOES NOT PROTECT the generator itself. Overloading, short circuits, and a faulty condition in the battery may cause the generator to deliver an excessive amount of current. Many circuits are provided with fuses to prevent this condition. Others make use of a current regulator.

The construction of the unit in figure 79 is similar to that of the vibrating voltage regulator. The regulator coil, however, consists of a few turns of heavy wire, and the unit as a whole is placed IN SERIES WITH THE LOAD CIRCUIT. The contact points are bridged across a regulating resistor in the field circuit of the generator. The

control action of the field resistor is similar to that of the voltage regulator.

The current regulator operates on the principle that load current is proportional to load voltage. Therefore, excessive load current can be reduced by lowering the generator terminal voltage below the value maintained by the voltage regulator.

The contact points normally ARE HELD CLOSED. When they are closed, the regulating resistor shunting the points is short-circuited and the ONLY RESISTANCE IN THE FIELD CIRCUIT is that of

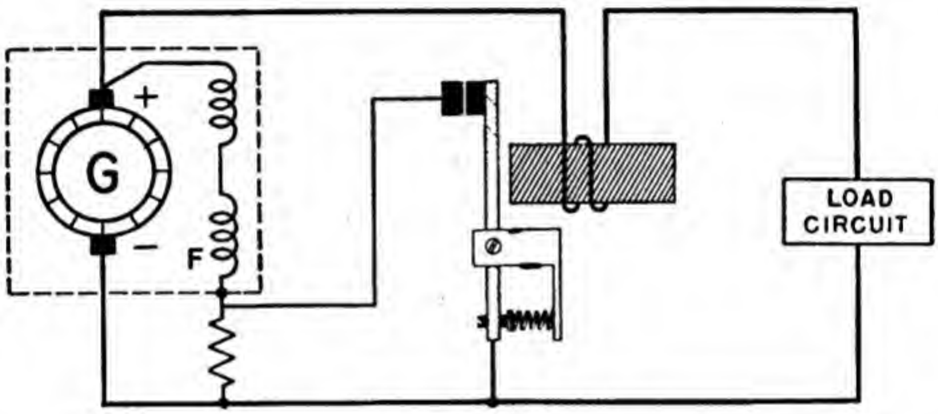


Figure 79.—Vibrating current regulator.

the field winding. The full load current of the armature passes through the main coil of the regulator. When this current is below the maximum rated current of the generator, the regulator points remain closed.

If the load current is above the maximum rated current, the REGULATOR POINTS OPEN. Separation of the contacts places the regulating resistor in the field circuit. The action reduces both the induced emf and the terminal voltage of the generator. Since load current is proportional to the generator terminal voltage, the load current is thereby decreased. The reduction in load current permits the spring to close the points again. The generator terminal voltage and load current again

increase, and the points open. This cycle of operation is repeated many times per second. Thus, the load current is controlled—it never exceeds the current rating of the generator.

REGULATION BY COMBINATION

The voltage regulator, current regulator, and cut-out relay are often included in one unit. Figure 80 is a schematic diagram showing the con-

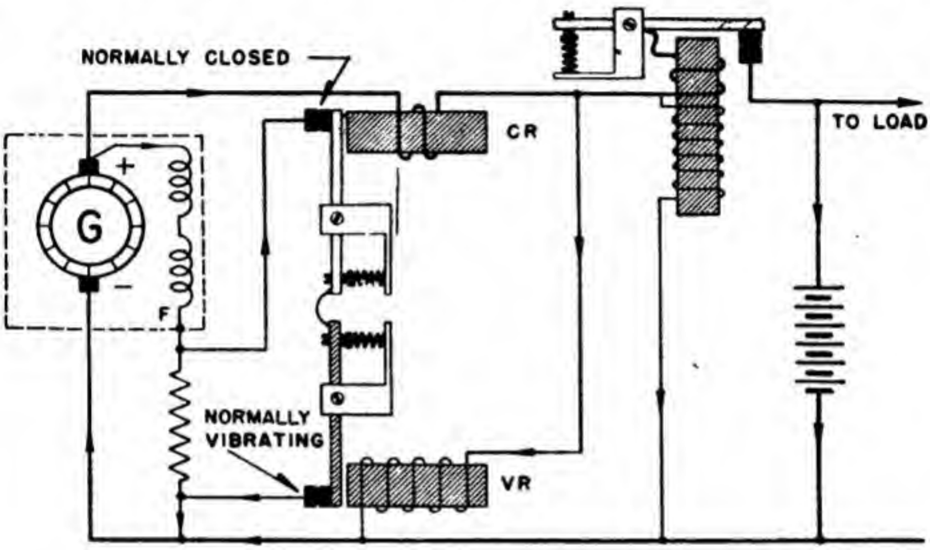


Figure 80.—Combination regulator.

nection of all three of these in one electrical system. In this particular circuit, both regulators operate on the same regulating resistor. The resistor is shunted by a series connection comprising the contact points of both regulators. The opening of either set of contact points places the regulating resistor in the field circuit. Under normal operating conditions, only the voltage regulator points vibrate. The current regulator serves as a SAFETY DEVICE for the generator. It functions ONLY if the load current becomes too high.

In certain types of regulators the regulating field resistors is divided into two sections. One

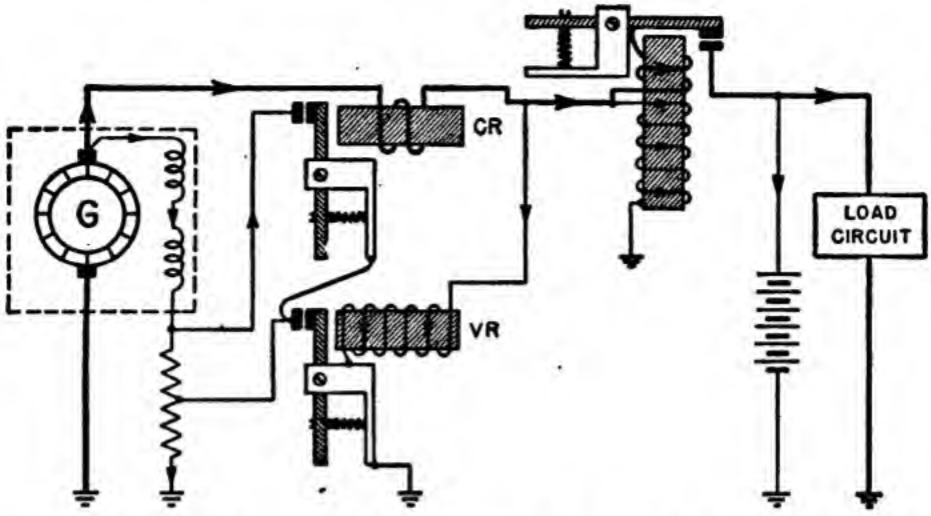


Figure 81.—Regulator in negatively grounded system.

section is bridged across the voltage regulator contact points. The other is bridged across the current regulator contact points. Figure 81 illustrates this type of regulation unit in a negatively grounded system.

G. E. MODEL 3GBD1A18 REGULATOR

Figure 82 shows the simple electrical equivalent of the regulator circuits for a G. E. Model 3GBD1A18 generator-voltage regulator. In operation this regulator maintains a constant out-

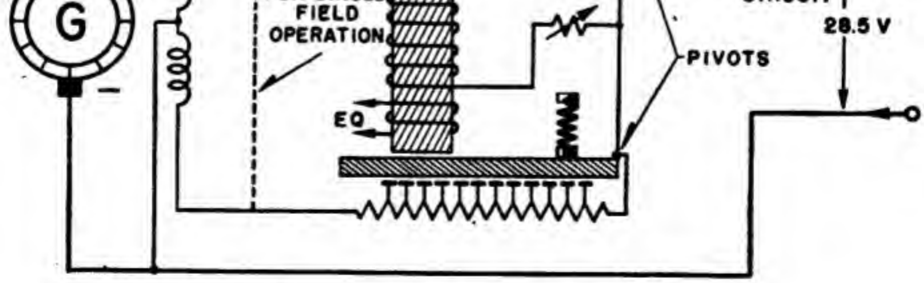


Figure 82.—G. E. regulator.

put of 28.5 volts. This output is adjusted at the factory. It may be used within a range of 26 to 30 volts d. c. The regulator also is used to equalize generator load in installations involving the uses of two or more generators connected in parallel.

Voltage control is achieved by a series of resistance steps in the regulating resistor. The resistance steps are introduced into, or shorted out of, the generator field circuit by a set of 24 CONTACT FINGERS and a silver contact bar. The contact fingers are operated by an armature in the magnetic circuit which is energized by a pair of potential coils. The coils are connected through an adjustable resistor across the voltage to be regulated. A bimetal temperature compensator adjusts for changes in voltage due to temperature variations ranging from 40° to 50° C.

When the current through the potential coils becomes greater because of an increase in the speed of armature rotation, the regulator armature is pulled toward the pole pieces. The motion raises the FINGER-LIFTER which, in turn, removes the contact fingers, one by one, from the contact bar. As the contact fingers are lifted from the bar, resistance is introduced into the generator field circuit. The action decreases the generator output, thus controlling the voltage. The current flows from the generator positive terminal to the contact bar and through the contact fingers to the regulating resistor. From there it goes to the field winding of the generator. When a finger lifts away from the contact bar, an element of resistance is introduced into the circuit. The maximum resistance in the field circuit is reached when ALL fingers are lifted from the bar.

The resistor in the regulator is arranged in two 36-ohm sections. The regulator is wired so

that by changing a terminal it is possible to use the regulator on either double-field or single-field generators. In the case of the single-field connection the two resistance sections are connected in parallel for a total of 18 ohms. This may be done WITHOUT ANY CHANGE IN EXTERNAL WIRING. It is also possible to obtain 72 ohms in a single circuit by making the proper changes in the external wiring.

The potential coil contains two windings. One of these serves to equalize the load carried by several generators operating in parallel. The flux of the equalizer coil, in combination with the flux of the second winding, changes the resistance in the generator field circuit or circuits. The change is made in such a way that the load is distributed in proportion to the generator ratings. The equalizer winding is energized by the voltage drop across the adjustable paralleling resistor. There is a connection from the negative brush of each generator to the negative bus. The drop is proportional to the load carried by each generator, provided that the paralleling resistors are properly adjusted. The resistors must be adjusted individually after installation in the aircraft to compensate for the differences between the wiring resistances and those of series fields on generators of different manufacture.

The regulator unit may be detached from the complete assembly without disturbing the remainder of the regulator assembly. It may be removed for testing or replacement by releasing the two Dzus fasteners.

CARBON-PILE RHEOSTAT

Figure 83 is a schematic diagram of an efficient type of voltage regulator. It consists of a CARBON-PILE RHEOSTAT inserted in the field circuit

of the generator. Field current in the circuit, therefore, is controlled by the resistance of the rheostat. The carbon pile itself consists of a series of carbon disks or wafers set in an insulated sleeve. One end of the sleeve is closed by a spring, controlled by the action of an electromagnet connected across the line.

The resistance from one end of the carbon pile to the other is determined by the spring tension. If the compression weakens, the carbon disks move apart. The disks only touch each other at certain points and increase the over-all resistance.

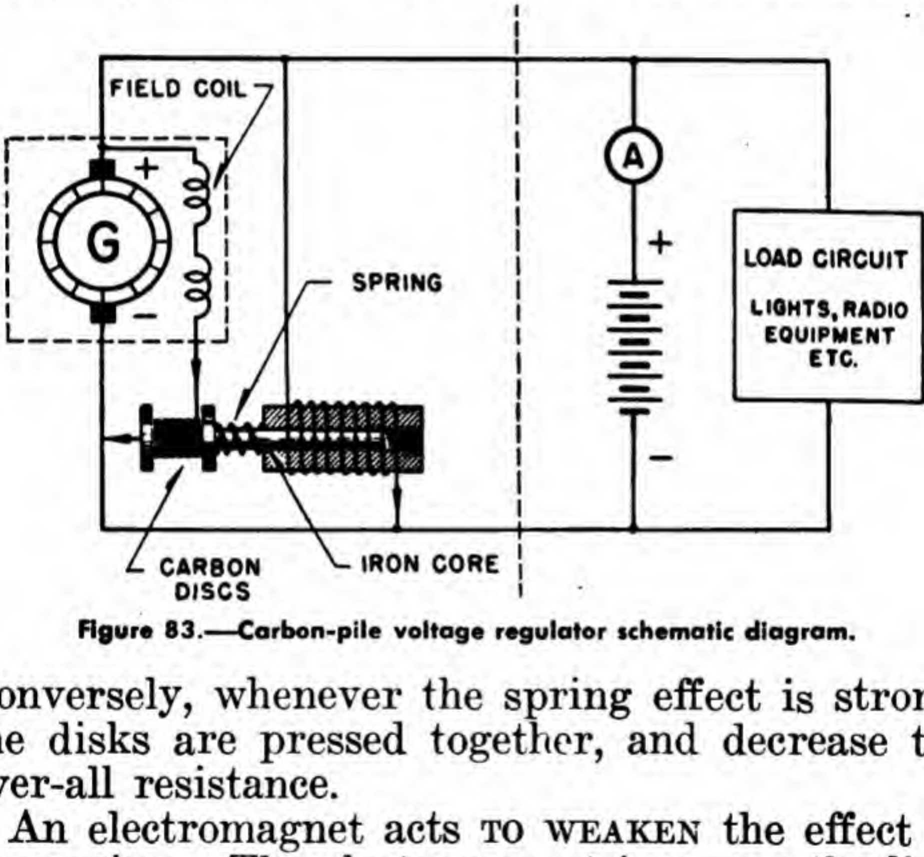


Figure 83.—Carbon-pile voltage regulator schematic diagram.

Conversely, whenever the spring effect is strong, the disks are pressed together, and decrease the over-all resistance.

An electromagnet acts TO WEAKEN the effect of the spring. The electromagnet is across the line. An increase in generator voltage also increases the current to the electromagnet. If the generator voltage raises the line voltage above the limiting value, the increased magnetic force attracts the iron core which eases the compression effect of the pile spring. The increase in resistance de-

creases both the field current and the flux produced by this current. Since the generator armature has less flux to cut, the induced emf of the generator decreases.

A condition of equilibrium is established between the opposing forces of the SPRING and the ELECTROMAGNET. The resistance of the pile is determined by the position which the spring assumes at the balance point. Any tendency toward increase in line voltage affects the balance point by increasing the strength of the electromagnet. Thus, the field current decreases as the generator speed increases. The result is a constant line voltage.

The diagram of the carbon-pile regulator shown in figure 83 is a simplified version of the actual regulator. But it illustrates the principle of operation.

ADJUSTMENT AND SETTING

SETTING the adjustable rheostat is the FIRST procedure when using a carbon-pile regulator. Two methods are in common usage—

The precision ohmmeter, and
The measurement of current flow method.

Figure 84 shows that two leads from the PRECISION OHMMETER are connected to the $A+$ and $A-$ plugs on the panel board. The lock nut on the rheostat adjusting screw is loosened. The adjusting screw is turned until the ohmmeter registers a reading of 52.8 ohms. NO FURTHER adjustments of the rheostat screw should be necessary.

Figure 85 shows the circuit arrangement necessary in order to adjust resistance of carbon pile by the CURRENT-FLOW METHOD. A variable resistor is inserted into the line in order to adjust the

voltage accurately to 28.5 volts. The steps in the procedure are as follows—

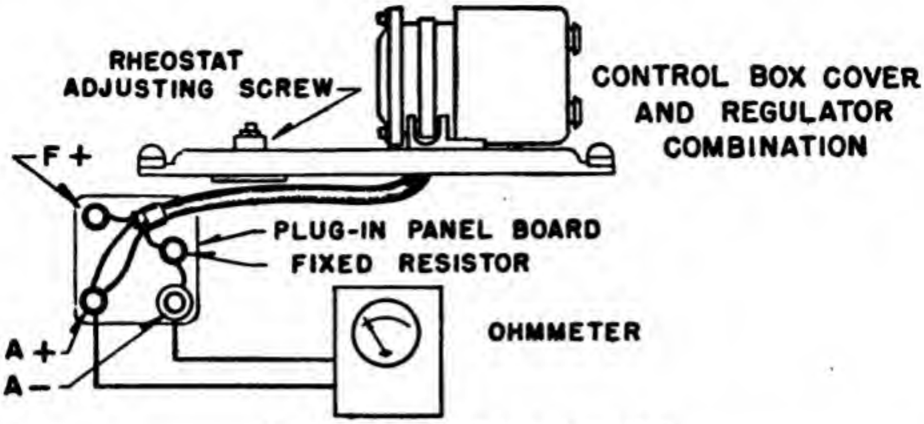


Figure 84.—Precision ohmmeter.

Adjust line rheostat until voltmeter reads 29.5 volts.

Loosen the lock nut holding the carbon-pile rheostat adjusting screw.

Turn the adjusting screw until the milliammeter reads 540±5 milliamperes, maintaining the voltage constant at 28.5 volts by means of the variable resistor.

Tighten the rheostat lock nut.

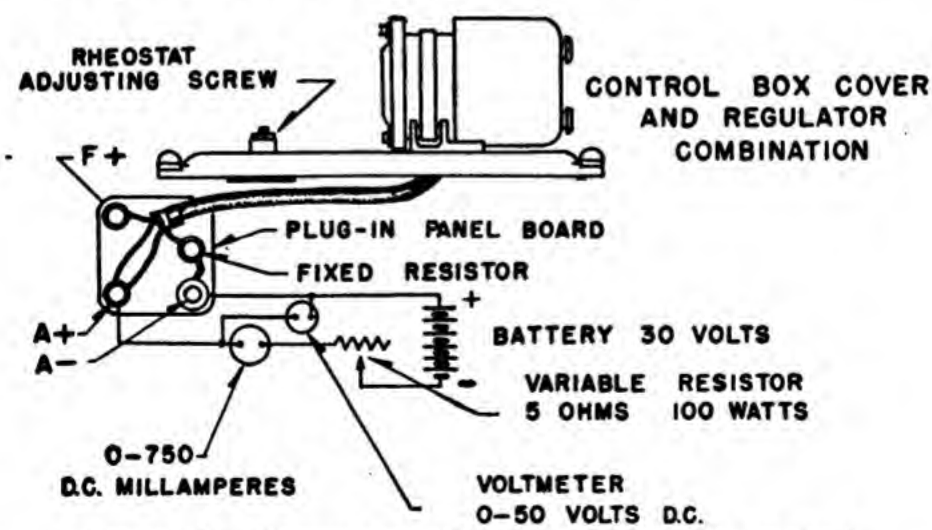


Figure 85.—Measurement of current by current-flow method.

The adjustment compensates for line resistance to the carbon pile.

Figures 86 and 87 show external and internal views of a carbon-pile regulator. And, figure 73 *A* and *B* shows the internal structure of the carbon-pile regulator.

Certain MECHANICAL ADJUSTMENTS must be made before the wiring can be completed. The core

Figure 86.—Carbon-pile regulator (exterior).

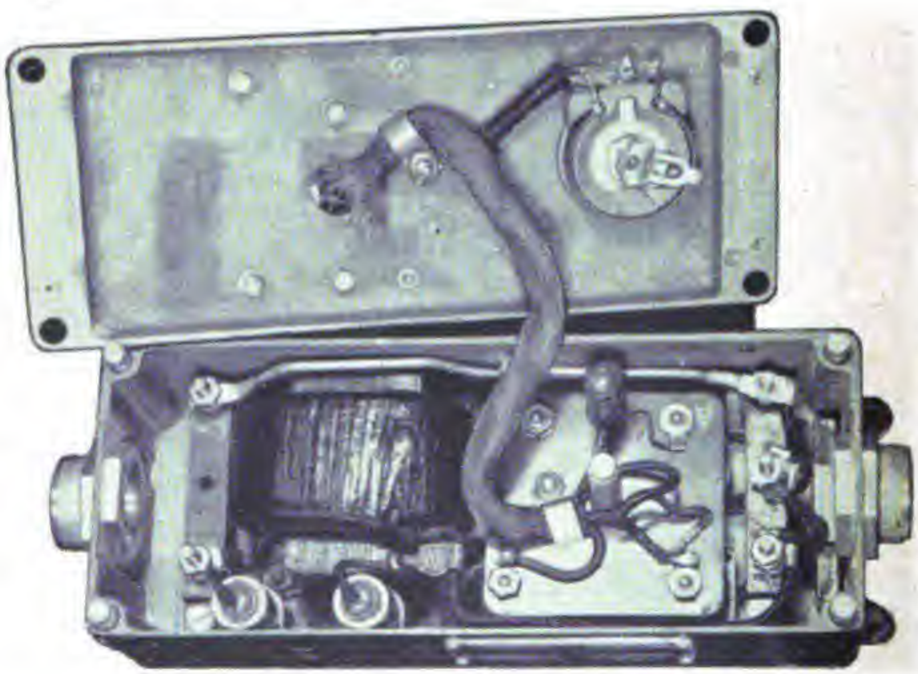


Figure 87.—Carbon-pile regulator (interior).

should be turned until the punch or chisel mark is in line with the corresponding mark on the back plate of the magnet housing. In order to do this, the core locking screws must first be loosened. The screws are tightened after the core has been alined. On the opposite end of the regulator is a dust cover secured by three knurled nuts. Remove these nuts in order to have access to the carbon pile locking screw. Rotate the carbon-pile screw in a counterclockwise direction until pressure on the spring is released.

Next rotate the screw in a clockwise direction until two-thirds of the length of any one spring arm is in contact with the spring support.

The ELECTRICAL ADJUSTMENTS on the carbon-pile regulator are made as follows—

Aline $A+$, $A-$, and $F+$ terminals on the control box cover and regulator combination with the corresponding plug-in prongs in the control box. Plug in the panel board assembly, shown in figure 89. Lock the cover of the control box.

Connect the control box containing the carbon pile regulator into the test circuit.

With no d-c load applied, bring the generator to a speed of 2,400 rpm, observing the output voltage of the voltmeter. If the output tends to rise above 28.5 volts, back the screw plug enough to maintain an output slightly below 28.5 volts. Generator speed must be maintained at 2,400 rpm.

With the generator running at proper speed, slowly back the pile screw until the voltmeter needle fluctuates rapidly (indicating instability of the regulator) or steadily approaches zero reading. If the condition of instability is reached, screw in the pile

screw until the voltmeter needle stops fluctuating. Lock the pile screw.

If the voltmeter needle steadily approaches zero, the direction of the pile screw rotation should be reversed. It should be turned inward slowly while closely observing movement of the voltmeter needle.

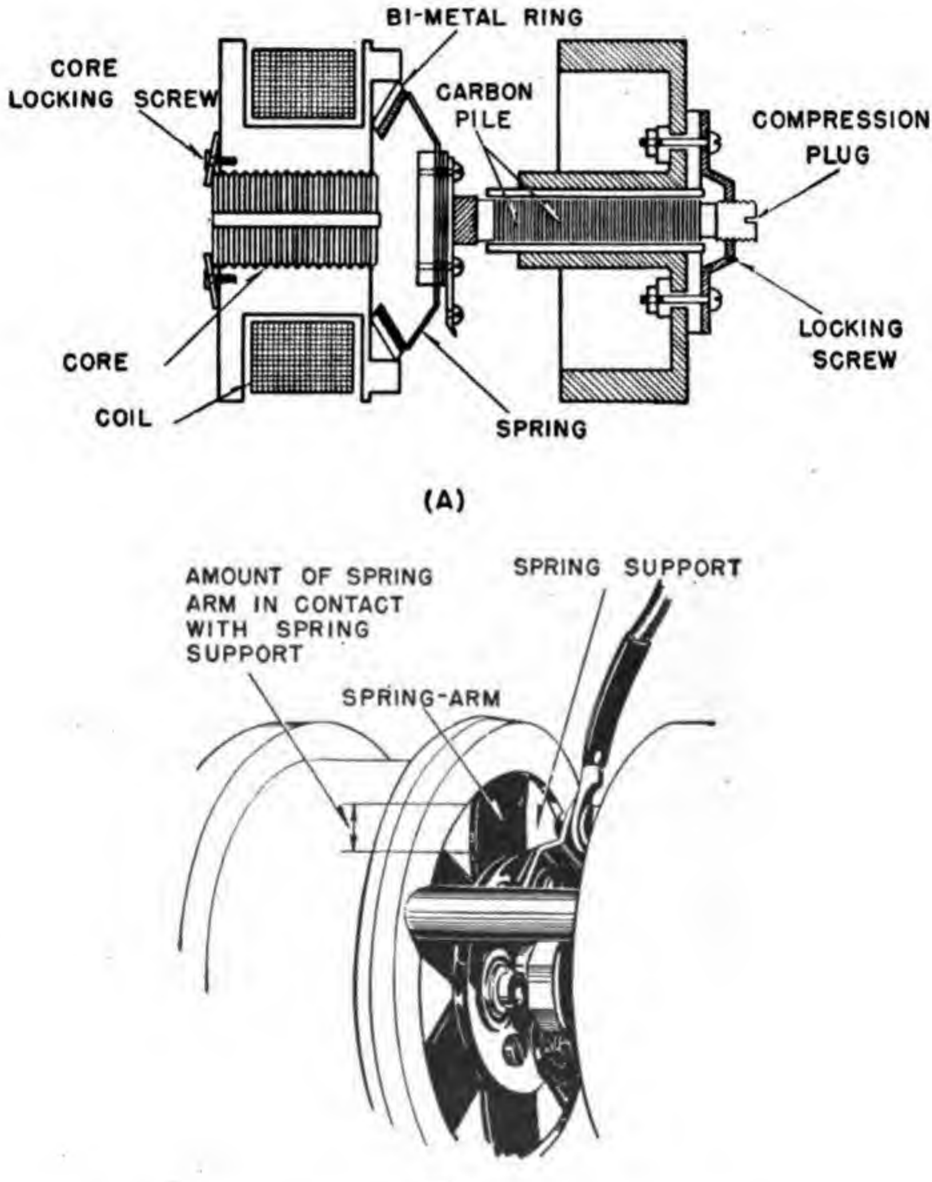


Figure 88.—Internal construction of carbon-pile regulator.

As illustrated in figure 90, the voltage rises to maximum when the pile screw is turned inward, drops off to a minimum and then begins to rise again. The best regulating position will be at a point just before the voltage reaches minimum. When making this adjustment, the pile screw should be turned slowly inward until the voltage passes through maximum and then through minimum. As the voltage begins to rise again, back the pile screw slowly outward until the voltage again passes through minimum and begins to rise.

LOCK THE PILE SCREW.

The curve is the characteristic voltage curve of the carbon pile regulator.

The voltage should read 28.5 volts after the pile screw has been adjusted properly. If the voltage differs, loosen core locking screws and slowly turn the core outward in order to raise the voltage, or inward, to lower the voltage to the required 28.5 volts. Tighten core locking screws.

It may be necessary to repeat adjustments (rotation of pile screw) several times until optimum adjustment of the regulator is obtained.

After all regulator adjustments have been completed, apply a d-c load of 5 amperes on the generator. The regulated voltage should remain at 28.5 volts. Vary the output load from 0 to 30 amperes. Voltage should remain stable. Vary the generator speed from 2,400 to 3,600 rpm. If the output voltage remains steady, the carbon pile regulator is ready for installation in an airplane.

Reinstall dust cover on regulator, tighten knurled screws.

Resetting the pile screw and core are FINE and SENSITIVE adjustments which must be carefully made. In making the necessary adjustments, do not rotate either the pile screw or the core more than one thirty-second of a turn at a time. Do

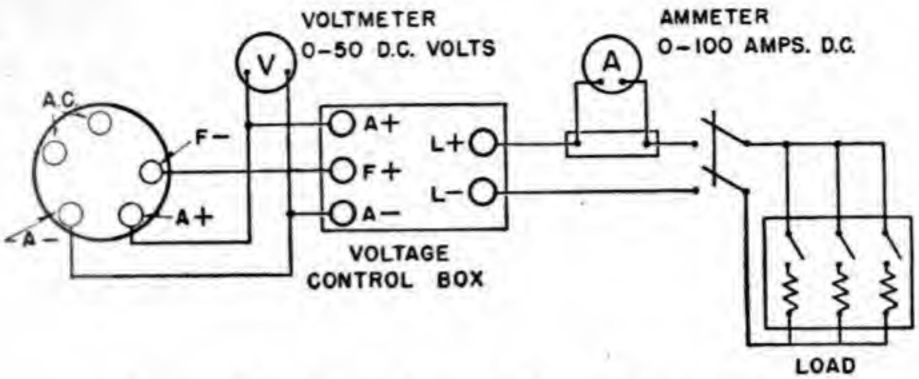


Figure 89.—Wiring diagram for setting carbon pile.

not loosen locking screw more than necessary as it will alter adjustment of the pile screw when retightened. Loosen pile locking screw only enough to turn pile screw.

The carbon pile regulator must be used with the same type of generator to which it has been adjusted on the test bench.

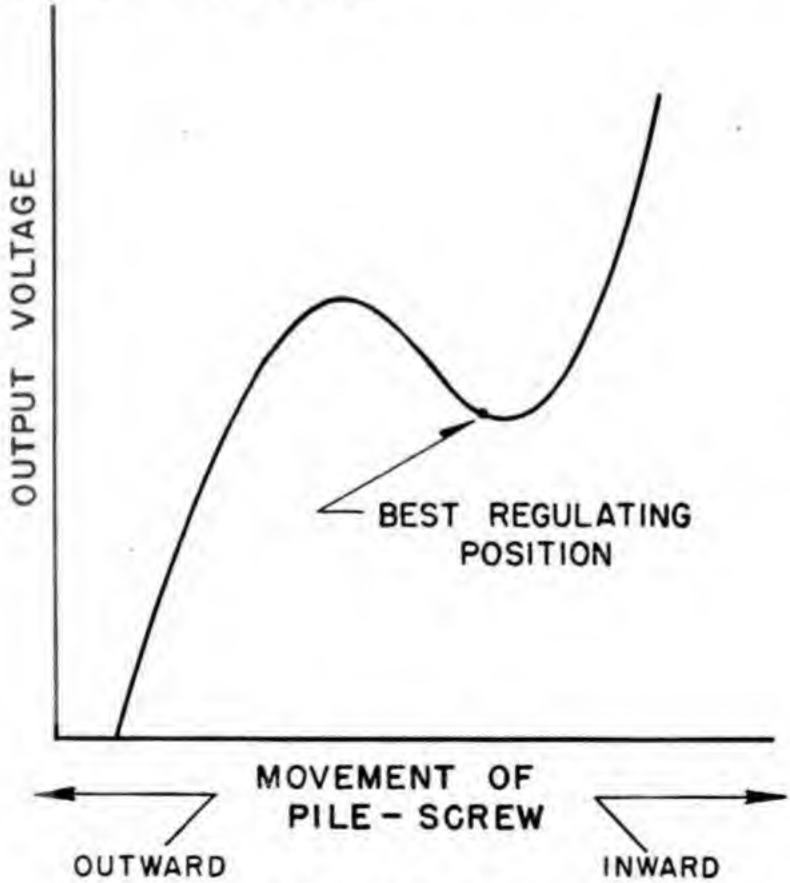


Figure 90.—Curve of voltage.

After all adjustments to the regulator have been completed on the bench, install it in the airplane. Increase the engine to a point where it drives the generator at 2,400 rpm or more. (The drive ratio of most engine-driven generators is approximately 1½–1. Therefore at an engine speed of 1,600 rpm, the generator is turning at 2,400 rpm.) Check the regulator from no load to full load at various generator speeds above 2,400 rpm. Check the voltage with an accurate portable voltmeter connected across the load side of the regulator. A properly set regulator shows a slightly higher voltage setting than 28.5 volts due to the increased resistance in the regulator coil circuit. This results from the long leads necessary in the airplane wiring.

The ADVANTAGES of the carbon-pile voltage regulator are—

- Regulation of the generated a-c and d-c output voltage is improved by reason of the continuous resistance change within the carbon pile.
- The resistance changes instantaneously in response to fluctuations of the generated output voltage.
- Radio interference is minimized due to the absence of movable contacts.
- Increased wattage capacity gives the regulator a greater range and allows regulation of higher field current generators.
- The carbon pile regulator is not affected by normal aircraft vibration or shock.

CHAPTER 10

SOURCES OF ELECTRICAL ENERGY

GENERATORS AND ALTERNATORS

What causes pulsating and alternating currents? What are the factors in back of the electrical energy produced in generators? You have learned that a generator produces direct current. You have also learned that a generator producing alternating current is known as an alternator. In this chapter you are going to discover some interesting characteristics of the generators used in Naval aircraft.

An alternator, driven at variable speed by an aircraft engine, is subject to the same voltage variation as a d-c generator. The FREQUENCY of the induced emf is also proportional to the speed. Although there is no simple method of controlling the frequency of an alternator driven at various speeds, it is possible to maintain a constant output voltage.

The field of an alternator must be supplied with direct current. The d-c voltage may be obtained from batteries, an external d-c generator, or a d-c generator on the shaft of the alternator.

A constant d-c voltage applied to the field of an alternator will not maintain constant voltage

output at the alternator terminals. Both the frequency and voltage magnitude change with speed. It is necessary to decrease field excitation as the speed of the alternator increases. A voltage regulator must be used with alternators even if a constant d-c voltage is applied to the field windings.

The schematic diagram of a self-excited d-c generator and a separately excited inductor type alternator is shown in figure 91 *A* and *B*. With this arrangement it is impossible to maintain con-

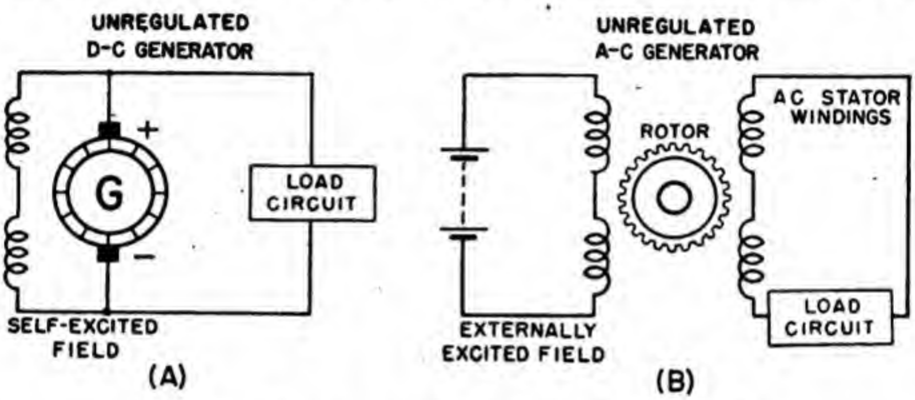


Figure 91.—A-c, d-c generator—Unregulated.

stant output voltage. In the alternator, the voltage output and frequency both increase with an increase in armature speed. In the d-c generator, the output voltage only increases with increase in armature speed.

In the alternator field circuit, the field voltage, field current, and flux density are all constant. In the d-c generator, the field voltage and field current vary with armature speed. Because of magnetic saturation in the iron, the flux density remains substantially constant when the generator reaches rated voltage. An increase in field current produced by an increase in armature voltage serves only to overheat the field windings.

After the magnetic saturation is reached, any increase in armature voltage is due to increase in

rate of flux cutting. Thus, the output voltage of both machines varies in the same way with change in armature speed over the operating range.

In figure 92 *A* and *B*, the machines shown in figure 91 *A* and *B* have been equipped with a means for regulating output voltage. The variable resistance in the field circuit makes it possible to vary the field current. By reducing the field current through an increase in field resistance, it is possible to maintain constant output voltage. Resistance variation in this case is a manual operation. Obviously in an airplane this system is impractical. It is necessary to use a system in which the field resistance variation is entirely automatic.

Voltage regulation of alternators is accomplished in much the same way as is voltage regulation in d-c generators, but with some additional equipment.

A separately excited inductor-type alternator, equipped with a vibrating-type voltage regulator, is shown in figure 93. The object of the regulator is to maintain constant a-c output at the terminals of the alternator. The a-c output is applied to opposite points of a bridge-type copper-oxide rectifier circuit. Current flow through the element of this circuit is possible only in the direction of the arrows on each copper-oxide element.

Whenever point *A* on the stator winding is positive, point *N* on the rectifier is also positive. Current flows to the regulator winding by means of the path from point *N* to point *Y* and returns to the negative side of the stator windings by means of a path from point *M* to point *X*.

Whenever point *A* on the stator winding is negative, point *X* on the rectifier will be positive. Current now flows to the regulator winding over a path from point *X* to point *Y* on the rectifier.

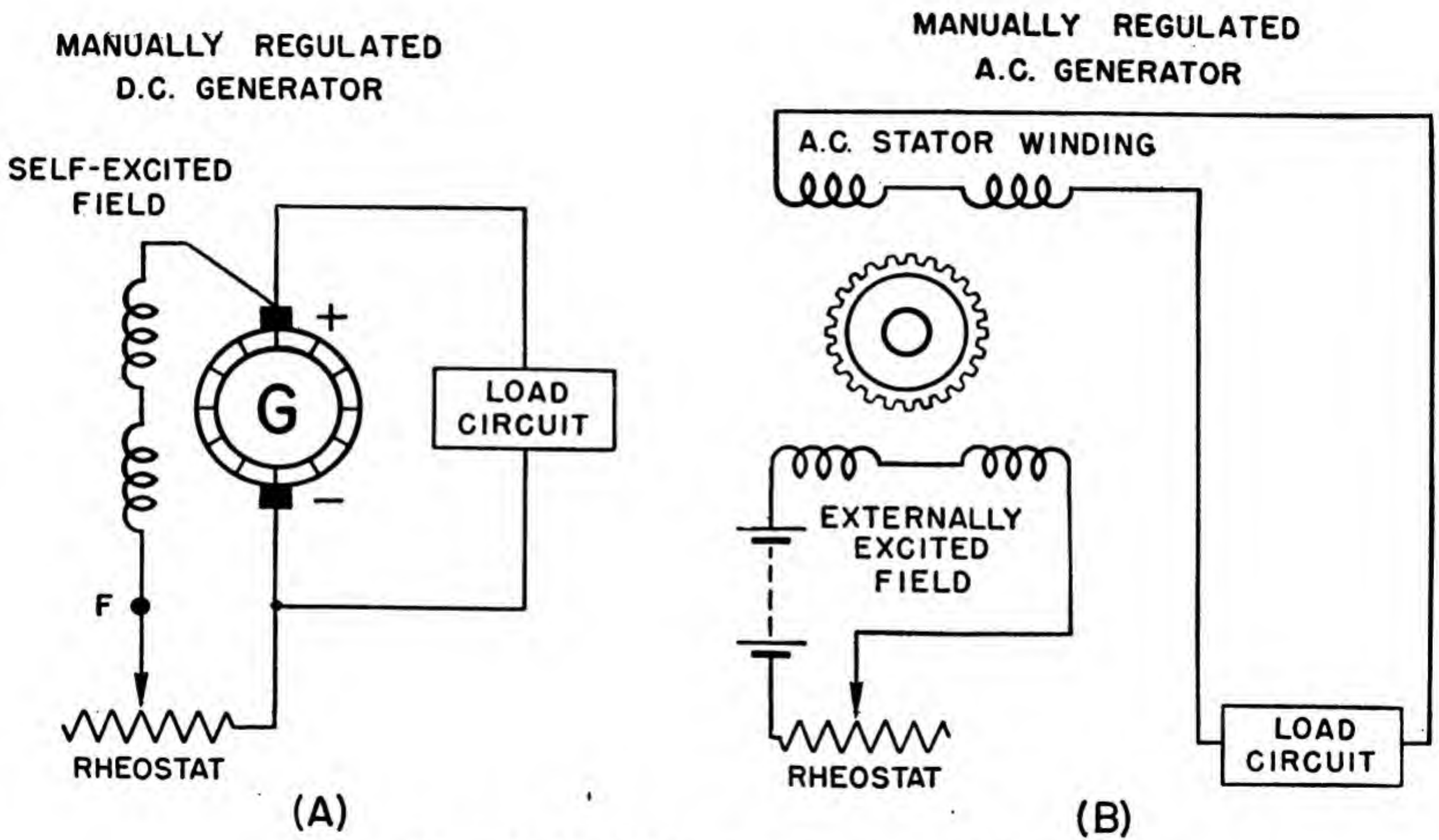


Figure 92.—A-c, d-c Generator—Manually regulated.

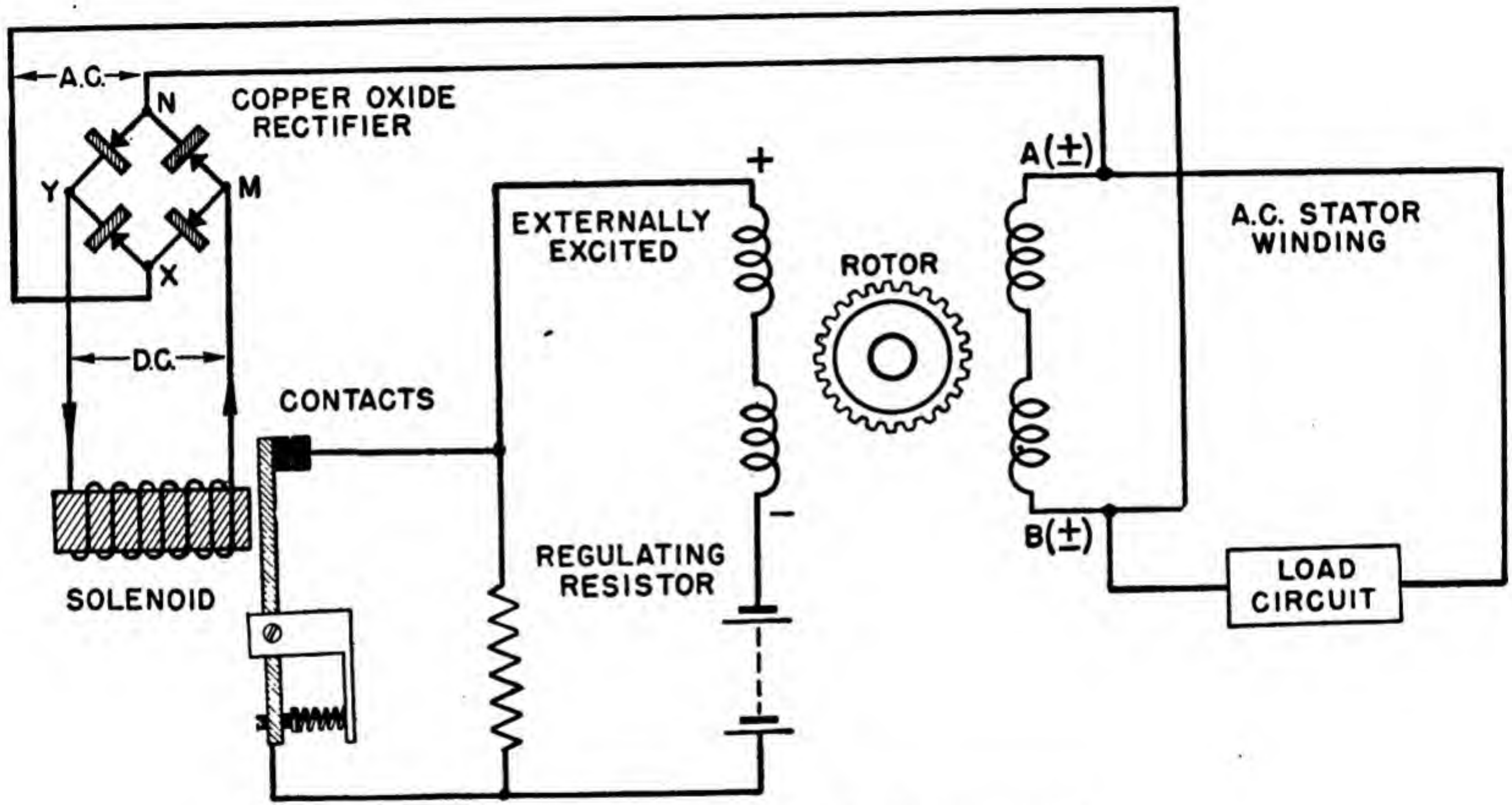


Figure 93.—Alternator regulator (vibrating contact type).

It returns to the stator winding through the path between points *M* and *N* on the rectifier. Thus, the current through the regulator is a pulsating direct current. The STRENGTH OF THIS CURRENT IS PROPORTIONAL TO THE A-C STATOR VOLTAGE APPLIED TO THE LOAD CIRCUIT.

The spring of the regulator may be set to operate at a required load voltage. The procedure from this point is similar to that for regulation of a d-c generator. Operation of the contact points introduces resistance into the field

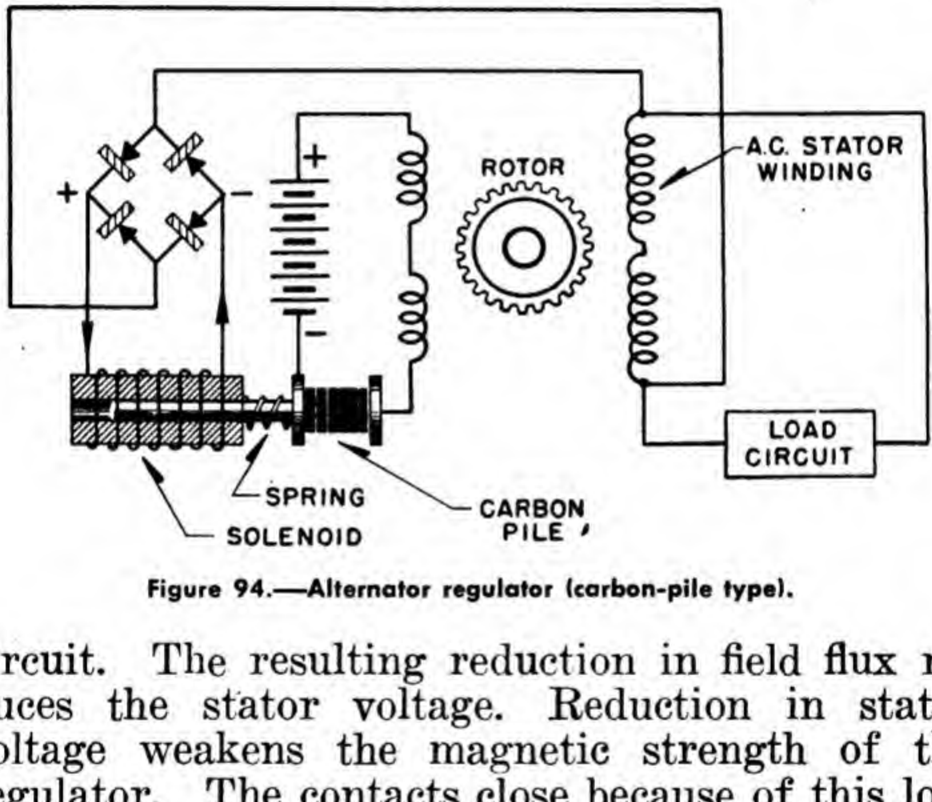


Figure 94.—Alternator regulator (carbon-pile type).

circuit. The resulting reduction in field flux reduces the stator voltage. Reduction in stator voltage weakens the magnetic strength of the regulator. The contacts close because of this loss in magnetic force and the stator voltage again rises. The action is repeated rapidly many times per second. The make-an-break action at the contacts maintains a constant AVERAGE value of the output voltage at the desired value.

In the circuit, a battery is used to furnish alternator field voltage. The voltage is usually obtained from a generator driven on the same shaft

as the alternator. A separate voltage regulator is used to maintain constant voltage from the generator. The constant value of d-c voltage replaces the battery voltage in the field circuit of the alternator.

Figure 94 illustrates the circuit diagram of the same inductor-type alternator with a carbon pile regulator in place of the vibrating regulator. The operation of the carbon pile unit has already been described. Its application in this circuit is self-explanatory.

GENERATORS

The ECLIPSE MODEL NO. 314 AIRCRAFT GENERATOR, figure 95, is a conventionally-regulated, shunt-field

Figure 95.—Aircraft generator—Eclipse Model No. 314.

four-pole unit. Rotation of the armature is obtained by direct drive from the aircraft engine. The generator is designed for use in aircraft requiring medium d-c power for the operation of radio and electrical equipment.

ELECTRICAL CHARACTERISTICS OF ECLIPSE MODEL No. 314—

d-c voltage, 30 volts.
d-c current, 50 amperes.
Power output, 1,500 watts.
Speed, 2,400/3,600 rpm.
Cooling, Fan.

Figure 96 shows a schematic wiring diagram of the generator. The voltage is controlled by regulating the amount of current flowing through the shunt field. The control action is obtained by means of an NF–2D voltage control box and a type 111144 carbon-pile voltage regulator which is adjusted to maintain the voltage constant at 28.5 volts. With this unit, the voltage remains constant from no load to full load, at generator speeds of 2,400 to 3,600 rpm. Using the carbon-

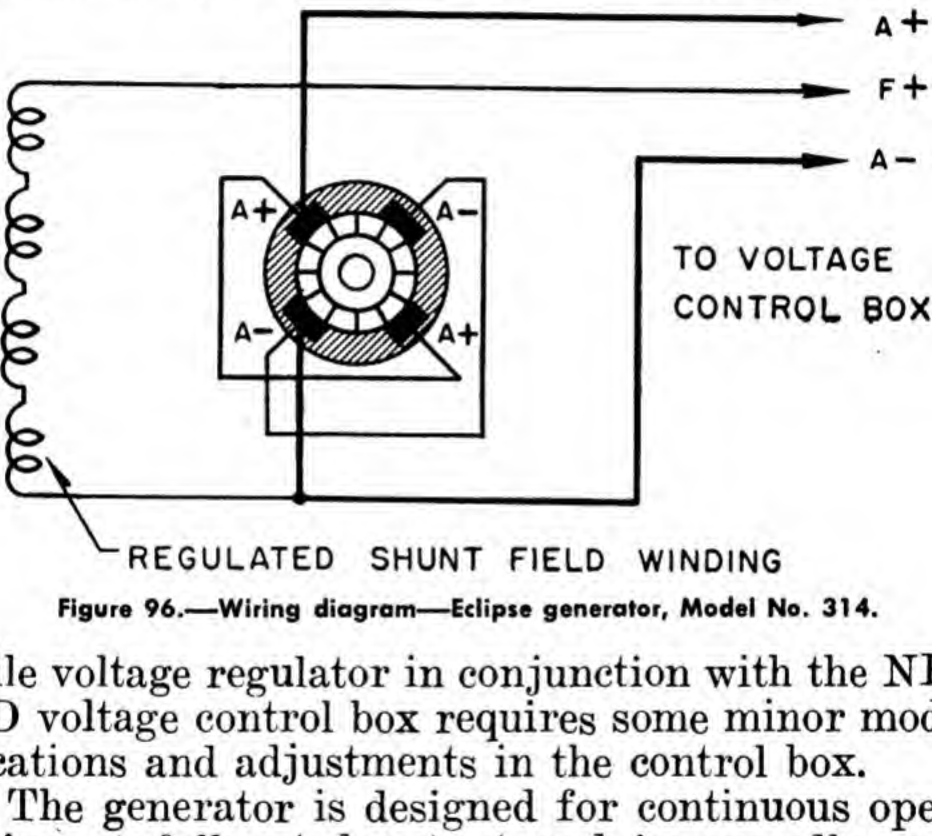


Figure 96.—Wiring diagram—Eclipse generator, Model No. 314.

pile voltage regulator in conjunction with the NF–2D voltage control box requires some minor modifications and adjustments in the control box.

The generator is designed for continuous operation at full rated output and is ruggedly constructed, both mechanically and electrically, to withstand vibration encountered on a shock mounted engine of high power output. It is provided with a flexible drive in the form of a flexible rubber coupling to absorb torsional vibration and power impulses from the engine, thereby preventing damage to the generator and excessive wear on the engine driving member.

The direction of armature rotation is indicated by an arrow etched into the metal surface of the front head bearing cap. The rotation of the generator armature is opposite to the engine drive rotation.

The GENERAL ELECTRIC MODEL 2CM70B1 D-C GENERATOR, figure 97, is a high capacity d-c generator used in aircraft usually equipped with a large amount of electric motor-driven equipment. A

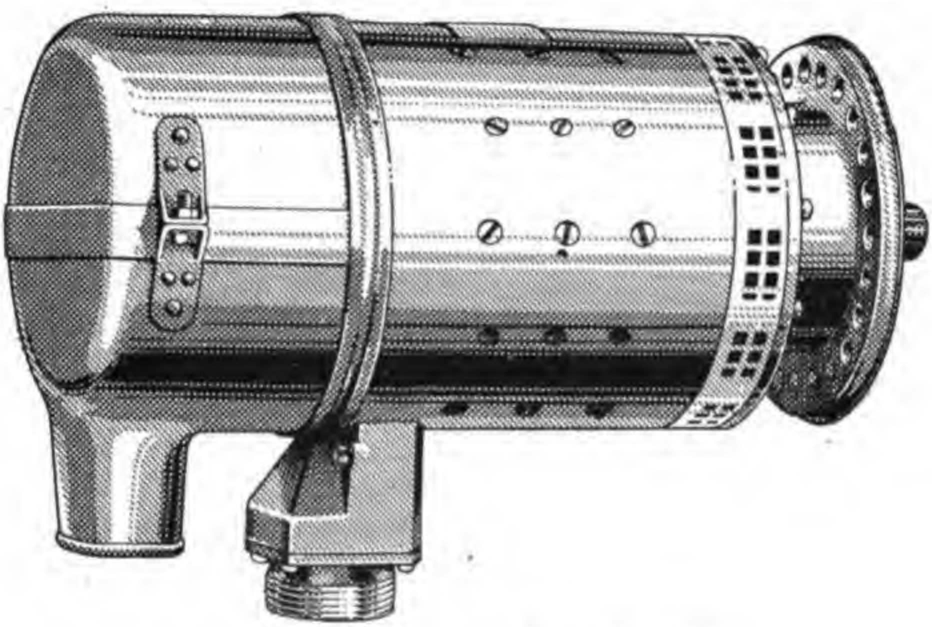


Figure 97.—Generator, Model 2CM70B1.

rotary converter usually supplies a-c power for operation of the radio transmitter. The conventional dynamotor is used for supplying high voltage for the radio receiver and its accessories.

ELECTRICAL CHARACTERISTICS OF G. E. MODEL 2CM70B1—

d-c voltage, 28.5 volts.
d-c current, 200 amperes.
Power output, 5.7 kilowatts.
Speed, 2,500/4,500 rpm.
Cooling, Air blast.

The FIELD CIRCUIT consists of a shunt-wound main winding, a compensating winding, and a commutation winding. The shunt field has six main poles. The compensating winding also consists of six poles.

The ARMATURE BRUSH ASSEMBLY is made up of six brush assemblies with two brushes in each assembly. Three of these brush assemblies are connected in parallel to form the positive terminal. The remaining three assemblies are connected in parallel to form the negative terminal. The six brushes carry the heavy current to both the positive and negative terminals. The construction of the principal subassemblies is shown in figure 98.

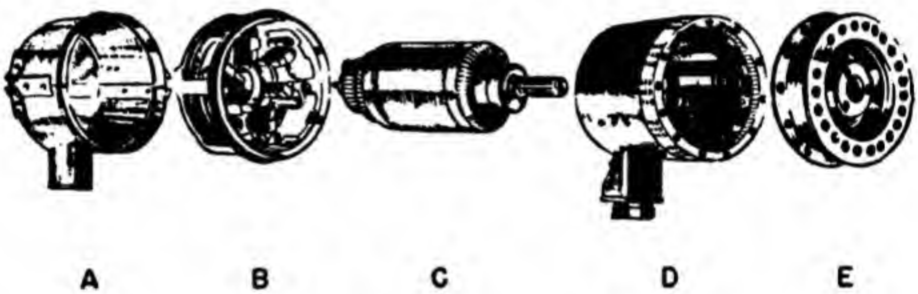


Figure 98.—Principal subassemblies of generator.

A PENCIL DRIVE SHAFT absorbs any mechanical shock which might be transmitted from the engine to the generator armature. The shaft is encased in a tube of asbestos which protects it from the high temperatures encountered. The splining of the shaft into the armature core at the anti-drive end assures positive drive.

The generator is cooled by an air blast obtained by mounting a funnel in the engine cowl section. The airstream is fed through a tube and cover cap into the anti-drive end of the generator. This forces the air through the generator, around the armature and field poles, and out through the exhaust openings at the drive end of the generator housing.

Voltage regulation is obtained through resistance control of the shunt winding by a generator voltage regulator.

The complete winding and connection diagram of the generator is shown in figure 99.

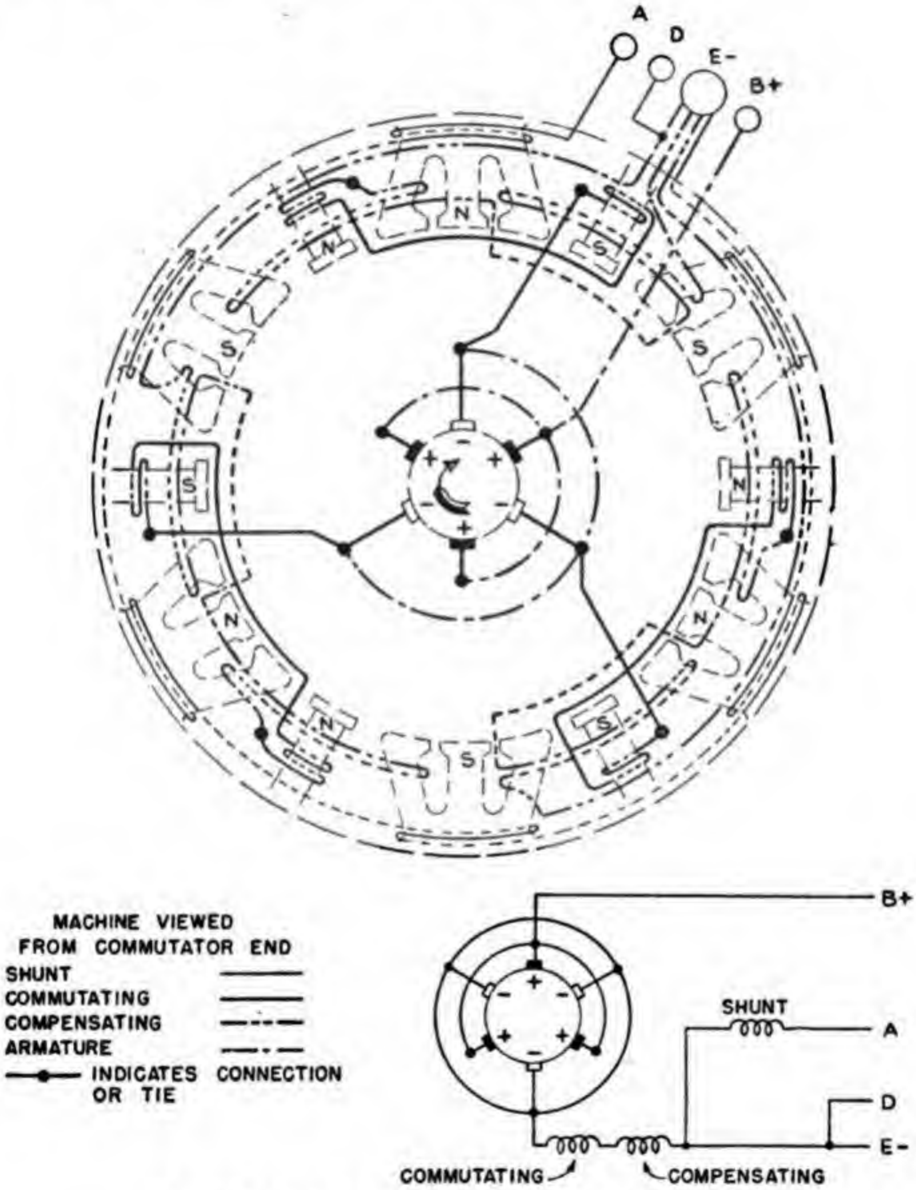


Figure 99.—Winding and connection diagram.

Three methods may be used to produce induced voltage—

BY CUTTING A MAGNETIC FIELD OF CONSTANT STRENGTH WITH A CONDUCTOR. In the case of

the generator, the conductors move, and the field is both constant and stationary. In the alternator, the conductors are stationary and a magnetic field of constant strength moves across the conductors.

By producing a collapsing and expanding magnetic field which cuts across a secondary circuit as in a transformer and ignition coil. In this case, the field strength is varied by

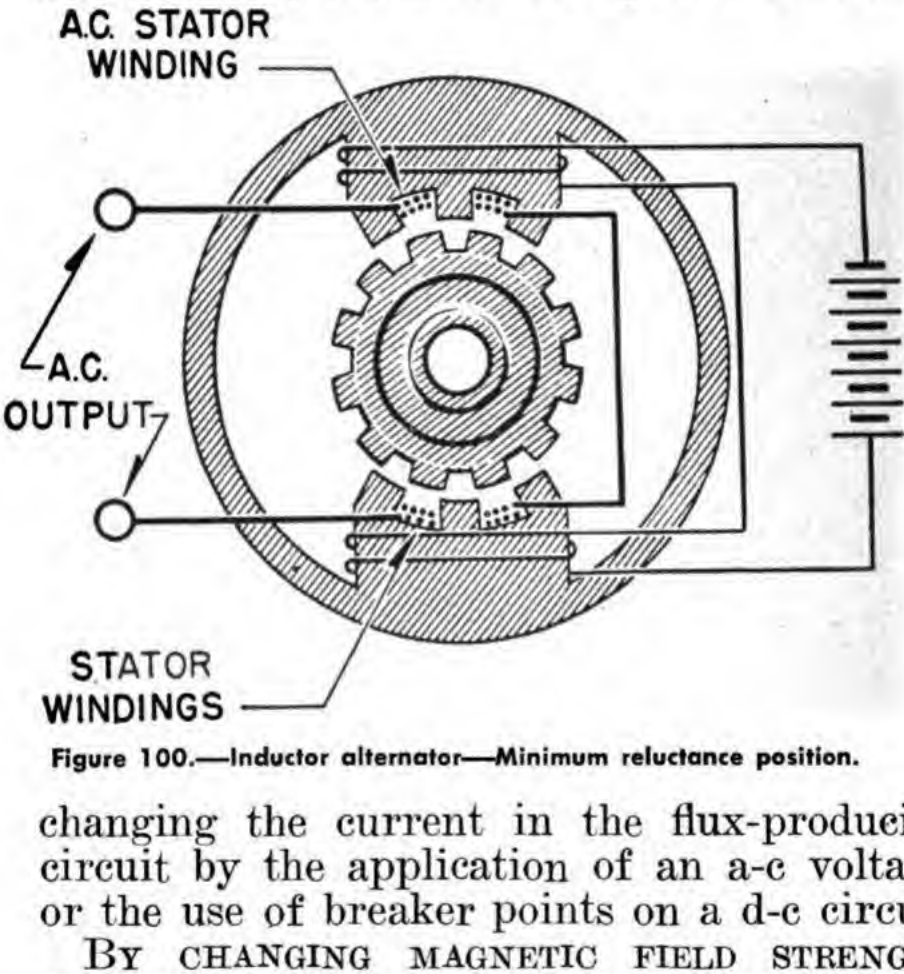


Figure 100.—Inductor alternator—Minimum reluctance position.

changing the current in the flux-producing circuit by the application of an a-c voltage, or the use of breaker points on a d-c circuit.

By changing magnetic field strength through change in the reluctance of the magnetic circuit, as in certain types of magnetos and alternators.

The d-c portion of an NEA–3 generator uses the conventional system employed in all d-c generators—that of cutting flux with conductors on a revolving armature. The a-c voltage in the

alternator section uses the third method. In the latter case the induced voltage in the stator winding is produced by a collapsing and expanding field which acts on the stator windings. The action occurs because of the cyclic variation in the reluctance of the magnetic circuit formed by the pole pieces and the revolving rotor.

The manner in which reluctance change is effected is illustrated in figure 100. A condition of minimum reluctance is obtained because of the small air gap between the teeth of the slotted

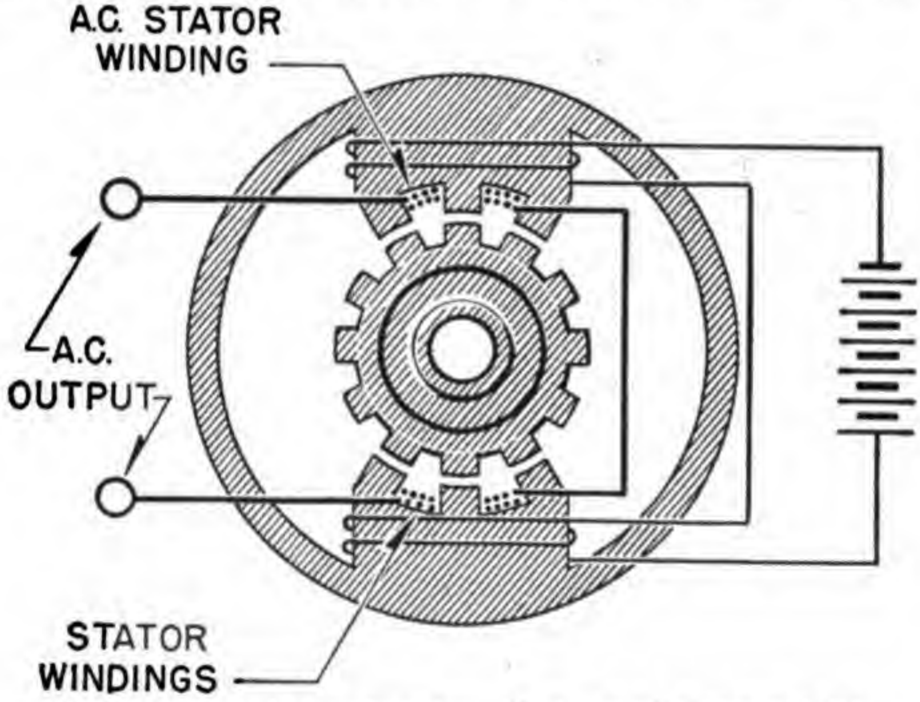


Figure 101.—Inductor alternator—Maximum reluctance position.

rotor and stator. The highest value of flux is obtained in this position.

In figure 101 the reluctance of a magnetic circuit is very high because of the comparatively long air gap in the magnetic circuit. A condition of minimum flux density is obtained in this position.

As the rotor revolves, the reluctance increases and decreases at a rate determined by rotor speed. The magnetic field is increased and decreased at the same rate. The action of this field induces

an a-c voltage in the stator windings at a frequency determined by rotor speed.

The NEA–3 GENERATOR, figure 102, is composed of two separate units mounted in a common shell. One is a conventional-type d-c generator consisting of a yoke, pole-shoes, shunt field, armature, and brushes. The other unit is an inductor-type alternator consisting of a stator, holding the a-c winding and a-c exciting field, and a rotor with no winding.

Figure 102.—External view—NEA–3 generator.

The d-c armature and a-c rotor are mounted on a common shaft and are driven by a pencil shaft splined to the armature at the anti-drive end of the generator. The mechanism uses either a 6- or 16-tooth drive spline. No constant speed mechanism is used as both the a-c and d-c outputs are externally controlled by separate carbon-pile voltage regulators. The output ratings of the NEA–3 are as follows—

D-C OUTPUT	A-C OUTPUT
Volts, 28.5.	Volts, 120.
Amperes, 60.	Amperes, 10–12.
	Frequency, 800.
	Watts, 1,200.
	Volt-amperes, 1,440.

Both units are provided with quick-disconnect plugs and are designed for use in insulated electrical systems.

The generator will develop its rated output voltage when driven at speeds of 2,400–3,600 rpm.

The generator may be mounted in any position, having 25/64-inch diameter mounting holes for attachment to an engine mounting flange.

All electrical connections are made through AN standard disconnect plugs. An air inlet for

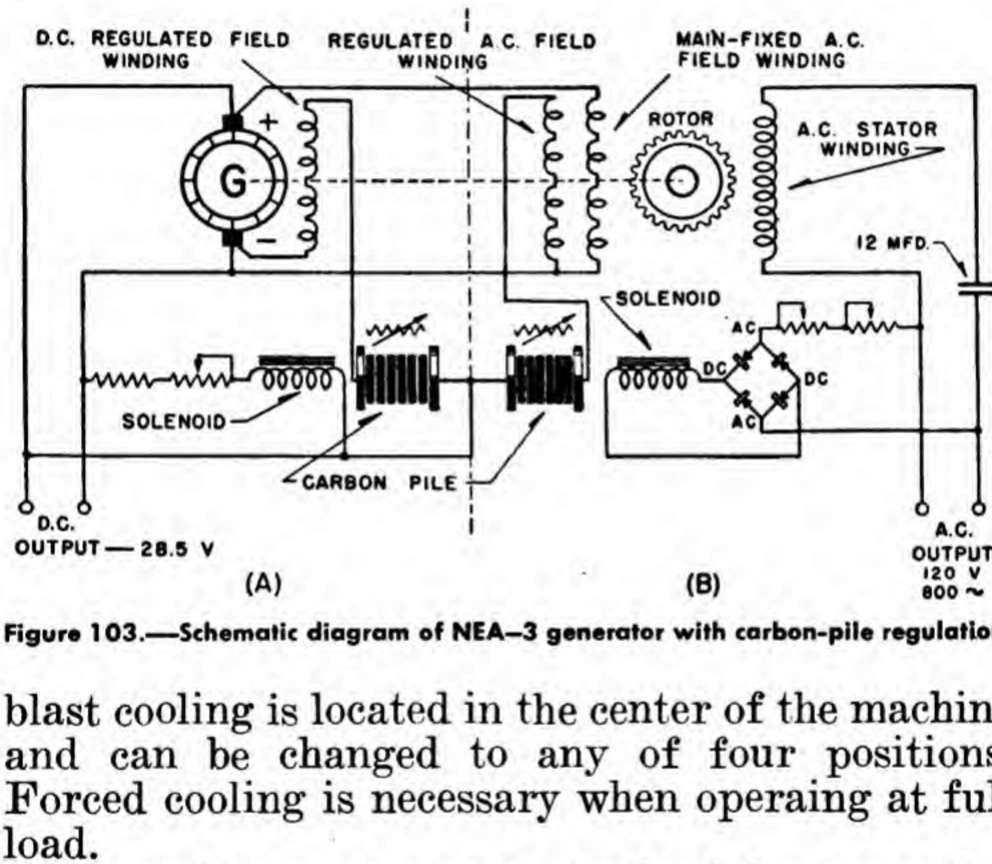


Figure 103.—Schematic diagram of NEA–3 generator with carbon-pile regulation.

blast cooling is located in the center of the machine and can be changed to any of four positions. Forced cooling is necessary when operaing at full load.

The unit operates as a standard d-c generator having a self-excited field, an armature, and brushes. The d-c output is controlled by a separately mounted carbon-pile control unit, figure 103 (*A*), which regulates the voltage output. The a-c output is generated by induction and is also regulated by a carbon-pile voltage control unit, figure 103 (*B*). The operation of all units is

automatic, depending only upon the aircraft engine for its drive. All wiring connections, and brushes should be checked after 50 hours of engine operation. Regulation of the generated output voltage is improved through use of a carbon-pile regulator.

The purpose of the NEA–5 generator is to supply a-c power for radio equipment and d-c power for battery charging, for motors, and for other d-c equipment. SPECIFICATIONS and preliminary instructions follow—

Speed range, 4,400 to 10,000 rpm.
d-c output, 200 amperes at 28.5 volts.
a-c output, 1,200 watts at 120 volts.
Frequency, 800 cycles at 4,000 rpm.

The a-c output is voltage-regulated, with the 1001–4–A carbon-pile control box. The d-c output is voltage-regulated, with the 1260–1–A carbon-pile control box.

The NEA–5 generator is a four-pole unit with an a-c alternator of the inductor type. The unit supplies a-c power for the radio equipment and d-c power for the entire electrical system. The mounting fixtures are applicable to the standard main-engine mounting pad. Two disconnect plugs are provided. One of these is for the d-c 3102032–1P, and the other for the a-c 3102–22–10S. The generator and the control boxes are completely shielded.

A nine-microfarad series condenser (paper, oil-filled type) with a peak voltage rating of 300 volts must be used with the alternator. The condenser can be located in the apparatus for which the power is supplied, or in the external a-c line.

Before running the generator with the control boxes installed, make certain that the wire from

the terminal on the output disconnect-plug of the a-c control box *B* is connected to the load side of the series condenser.

The a-c control box uses the conventional carbon-pile regulator which is actuated from a rectified a-c supply. An adjusting screw for making small voltage corrections is located on the side of the control box. If a correction of more than 10 volts is necessary, or if the voltage becomes unstable, send the control box to an overhaul station.

An AC 3102–22–10P disconnect-plug on the input, and a 3102–22–98 plug on the output are used on this box. The d-c control box also has a carbon-pile voltage regulator, but it is of larger capacity and is contained in a finned air-cooled housing. A voltage correction screw is located on the top cover of the control box. Instructions for use are similar to those given for the a-c control box.

An adjusting screw is located on the side of the a-c box. The screw is protected by a hexagon-shaped nut. It is used for adjustment when two or more generators are operated in parallel. The adjustment is made for equalizing the loads when the equipment is originally installed. They should not need further adjustment so long as the wiring is not disturbed. When changing the d-c voltage regulators for overhaul or other purposes, only the top half of the box should be removed. This leaves the bottom section, containing the paralleling control, in the airplane. Thus, it is not necessary to re-parallel the generators.

The following procedure should be employed when installing new equipment that is to operate in parallel—

- A d-c ammeter (0 to 250 amperes) should be installed in each of the positive output lines.
- Only two generators at a time should be paralleled. The No. 1 generator should be paralleled with the No. 2 generator. Then the No. 1 with No. 3, and No. 1 with No. 4—in case of a four-engine installation. The paralleling resistor should be adjusted on any pair of generators until the reading on the load ammeters is equal when each generator is carrying approximately 75 percent of load.
- The d-c control box has only one disconnect-plug, 3102–24–2P.

The control boxes may be mounted in any position, and should be located where they will not be subjected to oil or water spray. The generator bearings are sealed, and should not need servicing for the life of the bearing.

The NEA–2B and NEA–2D aircraft engine-driven generators were primarily designed for aircraft electrical and radio systems requiring 12 to 24 volts d. c. and 120-volt 800-cycle a. c. Twin-engine aircraft usually have one generator mounted on each engine. The ratings of the generators are as follows—

NEA–2B	NEA–2D
Volts, a. c., 120.	Volts, a. c., 120.
Amperes, a. c., 7–9.	Amperes, a. c., 7–9.
Watts, a. c., 840.	Watts, a. c., 840.
Voltamperes, 1,080.	Voltamperes, 1,080.
Frequency {800 cycles. 2,400 rpm.	Frequency {800 cycles. 2,400 rpm.
Volts, d. c., 14–14.6.	Volts, d. c., 28–28.5.
Amperes, d. c., 30.	Amperes, d. c., 25.

The splined end of the generator fits into a geared coupling on the engine. The coupling

has a step-up ratio of approximately $1\frac{1}{2}$ to 1. Therefore, if the engine is turning over at 1,500 rpm, the generator is actually turning at 2,250 rpm.

The generator, when operated at an engine drive speed of 1,500 to 1,800 rpm, will maintain the rated a-c output with one-half the d-c and full a-c loads. A reduction of the drive speed below the value for rated output will result in a decrease in frequency and d-c output. Further decrease in generator drive speed will result in decreased a-c output as well.

The generator has two shunt fields, one fixed and one regulated. It also has a fixed a-c or stator winding.

The a-c stator winding is wound parallel and adjacent to the shell of the generator in such a manner that the d-c field windings completely enclose the a-c stator winding. The a-c voltage depends not only upon the armature speed, but also the d-c load conditions as well.

The construction, size, weight, and mode of operation of the two generators are essentially the same. They differ only in the d-c voltage and current output. Therefore, the description which follows is APPLICABLE TO EITHER GENERATOR.

The six major assemblies which comprise the make-up of the NEA–2B and NEA–2D generators are—

The mounting head assembly is designed for installation on a standard circular flange containing six studs. The pilot flange assembly is secured to the rear of the mounting head with flathead screws. It consists of an oil-seal baffle, driving assembly, and a ball-bearing-mounted involute splined drive coupling. The pilot flange assembly transmits the drive to the rotor through the constant speed drive mechanism.

Two removable window straps are provided on the exterior of the mounting head. A perforated strap is located over the cooling fan at the mounting flange. It is fitted with a locating pin to prevent improper assembly. The solid strap is located adjacent to the intermediate head over the constant speed clutch adjusting mechanism. Adjustment of the clutch is permitted upon removal of the solid window strap.

The driven coupling and fan assembly are mounted on ball bearings held in place with a lock ring on the drive end of the rotor shaft. The fan assembly, consisting of 36 spot-welded vanes, is riveted to the outer flange of the driven coupling. The driven coupling assembly transmits the drive from the bronze clutch segments to the carbon-disk clutch plates of the constant-speed drive.

The constant-speed drive, or drive-sleeve assembly, consists of an adjustable carbon-disk clutch splined to the rotor shaft. The torque setting of the clutch is controlled by a series of counterweights, under spring tension, attached to the driving sleeve. The constant torque setting may be varied manually by rotating the adjusting cup assembly threaded to the counterweight plate.

The rotor, or armature assembly, serves as the rotating member for generating alternating current. The rotor acts also as the armature for d-c output.

The stator, or yoke assembly, consists of the a-c generator winding and the field windings. The field coils produce the electromagnetic flux necessary to provide a-c and d-c voltage.

The front head assembly consists of a housing containing the terminal board and d-c brush rigging.

Torque is transmitted from the engine to the generator by means of a carbon-disk clutch.

Friction in the clutch is controlled by a set of counterweights acting against spring tension. The action of the weights is governed by centrifugal force. When the application of torque brings the armature speed to its required minimum (2,400 rpm), centrifugal force moves the counterweights outward, overcoming the tension of the springs. This relieves the pressure between the carbon disks and bronze plates. The carbon disks are then free to slip between the bronze plates. The result is a decrease in transmitted torque, and a consequent decrease in rotor speed.

As the rotor speed decreases, the centrifugal force on the counterweights decreases and the spring tension causes the carbon disks to reengage. Thus by means of the carbon-disk clutch—more commonly called the constant-speed clutch—the speed of the generator armature is held constant. This speed is approximately 2,400 rpm under variations of load at engine drive speeds ranging from 2,000 to 4,200 rpm.

Standard practice is to adjust the constant-speed clutch on a generator test to 2,450 rpm under no-load conditions. Then a test is made from no-load to full-load, checking the speed at various load values with a tachometer. A properly operating clutch mechanism does not allow the speed of the armature to drop below 2,400 rpm when delivering full d-c and a-c load at the proper frequency of approximately 800 cycles.

A clutch with worn carbon disks allows the armature speed to drop slightly. It must not fall below 2,350 rpm. Further decrease lowers the generator frequency and output below rated requirements with attendant decrease in operational efficiency of all electrical and radio equipment.

Although speed regulation is obtained by means of the constant-speed clutch, it is necessary also to control and to regulate the voltage of the generator under conditions of changing load. A voltage-control box, containing regulator and filter units, is used for this purpose.

In the NEA–2D generator, voltage regulation is controlled by using the same type carbon-pile voltage regulator used for controlling the d-c output of the NEA–3 generator. Therefore, all adjustments as previously outlined are strictly adhered to when adjusting the d-c voltage regulator within the NEA–2D.

This generator differs from the NEA–3 in size and output ratings.

No separate voltage regulator is used for control of the a-c output of the NEA–2D generator.

Only the d-c voltage is regulated. It is necessary to parallel and regulate both field windings to obtain proper voltage regulation.

The NEA–2D generators were originally designed to operate with the vibrator type voltage regulator. Therefore, when the No. 111144 carbon-pile voltage regulator is used, changes adapting the units to operate with the carbon-pile voltage regulator are made. The procedure is as follows:

> No change is necessary in the NF–1D voltage control box because one field resistor lead is electrically connected to the *R* terminal in the control box. This terminal is not utilized in the carbon-pile circuit.
>
> Remove generator terminal cover (end bell) and disconnect jumper strap from terminal *A*+ and *R*.
>
> Make a new jumper strap using No. 10 wire and insulate with a varnished cambric sleeve. Solder proper lugs on both ends. Connect to

terminals R and $F+$. This places both fields in parallel for simultaneous effective regulation.

Adjust carbon-pile regulator as outlined in section on adjustment of d-c carbon-pile voltage regulator.

NEB–1D AIRCRAFT GENERATOR (AUXILIARY)

The NEB–1D aircraft generator was designed for use on either type NEG–1A or type NEG–2

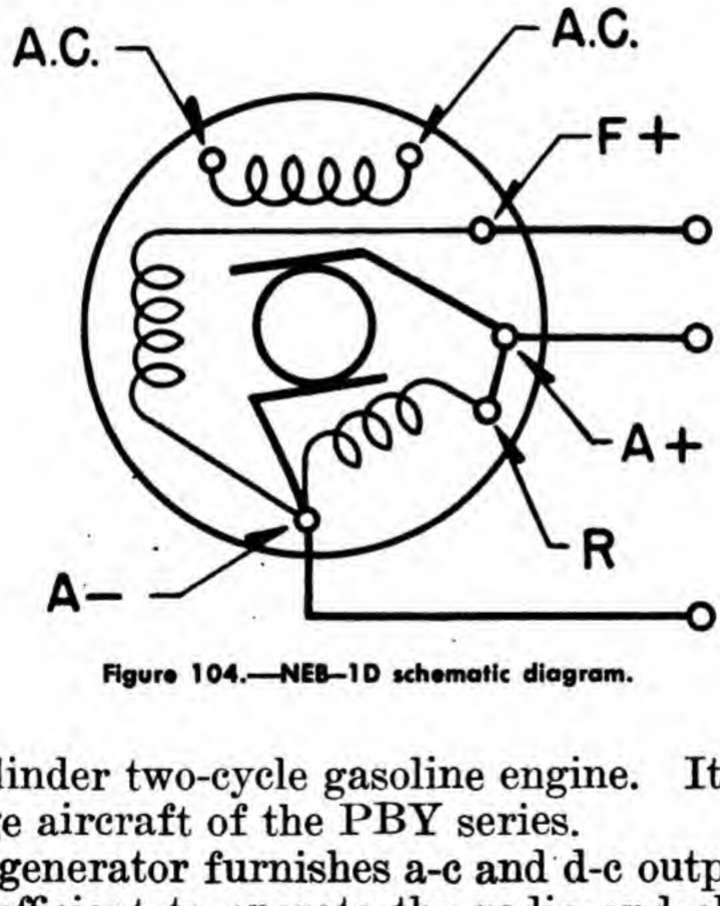


Figure 104.—NEB–1D schematic diagram.

one-cylinder two-cycle gasoline engine. It is used in large aircraft of the PBY series.

The generator furnishes a-c and d-c output voltages sufficient to operate the radio and electrical equipment of the airplane on a ground test with the engine-driven generators at rest.

It is a conventional self-excited shunt field generator containing a regulated and fixed shunt field. (See fig. 104.)

The ratings of the NEB–1D generator, when driven at a speed of 3,800–4,200 rpm, are—

Volts, d. c., 28.5.	Watts, a. c., 600.
Amperes, d. c., 60.	Voltamperes, 840.
Volts, a. c., 120.	Frequency {800 cycles.
Amperes, a. c., 5–7.	Frequency {4,000 rpm.

The generator is driven directly by the gasoline engine, which is usually adjusted to run at 4,000 rpm for optimum results.

The voltage-control box NF–2D, is used with the NEB–1D generator. This control unit may be used with the No. 111144 carbon pile. With one minor change in the control box, the carbon-pile regulator may be used. It is necessary only to remove the electrical connection between the 60-ohm resistor and the *A* terminal. Tape up the end and install the d-c carbon-pile regulator in the control box.

Adjustments to the d-c carbon-pile unit are exactly as previously outlined. The generator does not have separate regulation of the a-c output voltage.

CHAPTER 11

TESTING

AN OUNCE OF PREVENTION

All testing is a safety measure—a sort of sleuthing, the results of which enable one to determine what is wrong or what may go amiss at a critical time. Various techniques have been devised for making tests with respect to electrical equipment. In this chapter you will get acquainted with some of the procedures used frequently in testing armatures and fields.

From the electrical standpoint the two most essential parts of a motor or a generator are the armature and the field. The d-c shunt motor and d-c shunt generator are most commonly used in Naval aircraft. The armature in both machines is most susceptible to damage. The reason is found in the brief analysis of the circuit diagrams which follow.

A d-c shunt motor is represented in figure 105*A*. The voltage applied to the field is equal to the impressed voltage and therefore is constant. Because the field is only a coil of wire on an iron core, the resistance also is fixed. Thus, the field current is nearly constant at all times.

The armature current, however, depends on the load. The motor speed tends to fall when the load is applied to the shaft. It then develops less counter-electromotive force and the armature current rises. If the load on the shaft is excessive, the armature current is also excessive. In such cases the armature windings are subject to damage from overheating.

Figure 105*B* shows the schematic diagram of a d-c shunt generator. If the generator is equipped with a voltage regulator, the terminal voltage is practically constant. As in a motor, the field

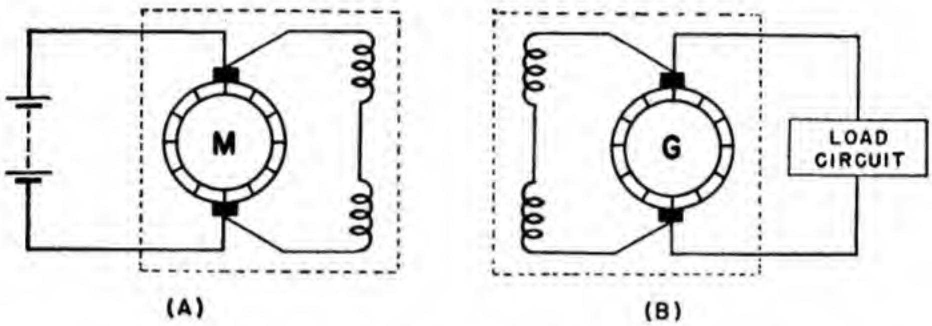


Figure 105.—D-c Shunt Motor and d-c Shunt Generator.

resistance is constant also. For this reason the field current remains at a fixed value and the field winding is not likely to be damaged. The armature of the generator supplies both the load current and the field current.

The field current is nearly constant, but the load current is determined by the condition and number of devices in the load circuit. A faulty cell in the battery also can increase the load current greatly. A short circuit can do likewise. It is possible to increase the load current by adding more devices. In all cases the excessive current passes through the generator armature.

It is apparent, therefore, that in both d-c shunt generators and motors, the armature and not the field is most likely to be damaged. This does not

hold true for d-c series motors. In the latter case, the field and armature have the same current. The field is more likely to be troublesome in this type than in the shunt type.

The various tests which may be used to determine the condition of an armature are—

- Ground tests—to indicate the insulation resistance with respect to the metal frame.
- Open tests—to indicate continuity of the armature windings.
- Short tests—to determine the insulation resistance of the windings with respect to each other.

ARMATURE GROUND TESTS

A common failure of armatures is the breakdown of insulation between the windings and the iron rotor, usually caused by overheating and charring the insulation. Inspection of the commutator of such an armature will show a badly pitted or burned section. The burned area corresponds to the point at which the grounded coil is connected to the commutator bars.

Most aircraft electrical systems are of the SINGLE-WIRE type with one side of the line grounded. In such an arrangement, the grounded armature places a partial short circuit across the supply line. This occurs when the commutator segments attached to the coil are under the grounded brush. At all other times, a short exists across a part of the induced emf in the armature and the efficiency of either a motor or generator is reduced.

To test an armature for grounds, a continuity tester, such as an ohmmeter, is used in order to check the resistance between each segment and the shaft, as illustrated in figure 106. The disadvantage of this test is the small voltage applied

by the ohmmeter. A true indication is not obtained if the insulation is sufficient to withstand the small test voltage.

A more reliable test for grounds is to use a supply source of 110 or 220 volts, and a lamp. This test places a high voltage between the armature winding and the core. The applied voltage breaks down any weak point in the insulation and current flows in the circuit. As a result of the completed circuit, the lamp glows.

A disadvantage of the test is that a comparatively strong current must flow through the filament of the lamp before it will glow. The amount

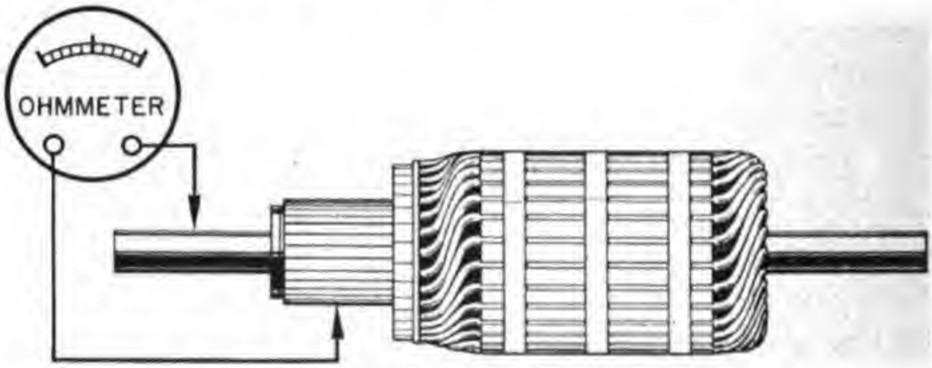


Figure 106.—Testing an armature with an ohmmeter.

of current required to give an indication depends upon the rating of the lamp used for the test. High resistance grounds therefore will not be indicated by this test.

The disadvantage is overcome by connecting an ammeter in series with the lamp as shown in figure 107. The ammeter should be capable of measuring the maximum current to the lamp. With this arrangement, the ammeter registers even though the current is not strong enough to illuminate the lamp. The lamp, however, safeguards the ammeter by limiting the maximum current flow in the circuit. In this way, indications are obtained for short circuits over a wide range of resistance values.

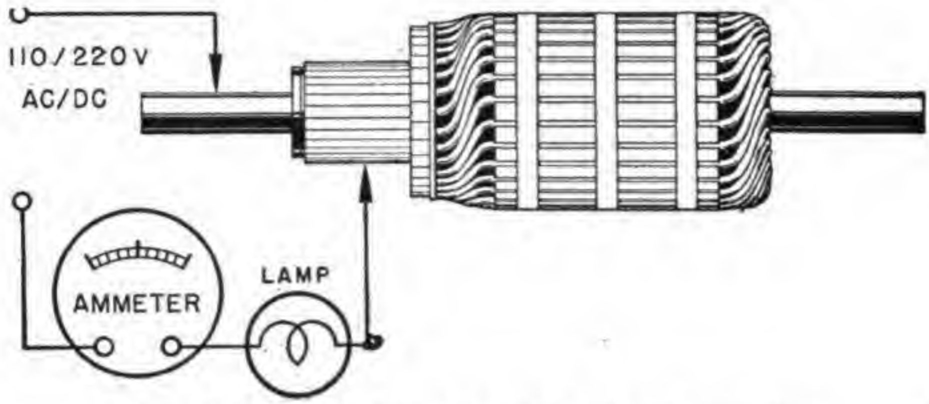


Figure 107.—Test procedure using lamp and ammeter.

ARMATURE SHORTS AND OPENS

In most d-c motors and generators, the individual coils of the armature are connected to commutator segments in order to obtain commutator action. Figure 108*A* represents a simplified diagram of the coils and commutator segments of a typical motor. Figure 108*B* shows that the circuit really is a series-parallel circuit, with respect to adjacent commutator segments.

If all coils are of equal resistance, the resistance between adjacent segments will be equal at any part of the commutator. For test purposes then, the armature may be considered to be a series of resistors connected to form a closed circuit between segments of the commutator. Resistance

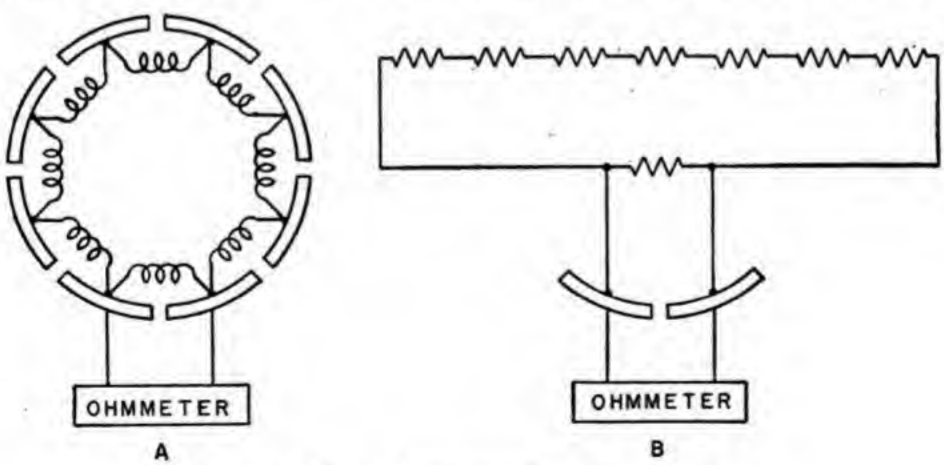


Figure 108.—Armature schematic diagram.

measurements taken between any two commutator segments may therefore be interpreted as an indication of the armature condition. A resistance test can be made with any type of resistance-measuring device, preferably an ohmmeter.

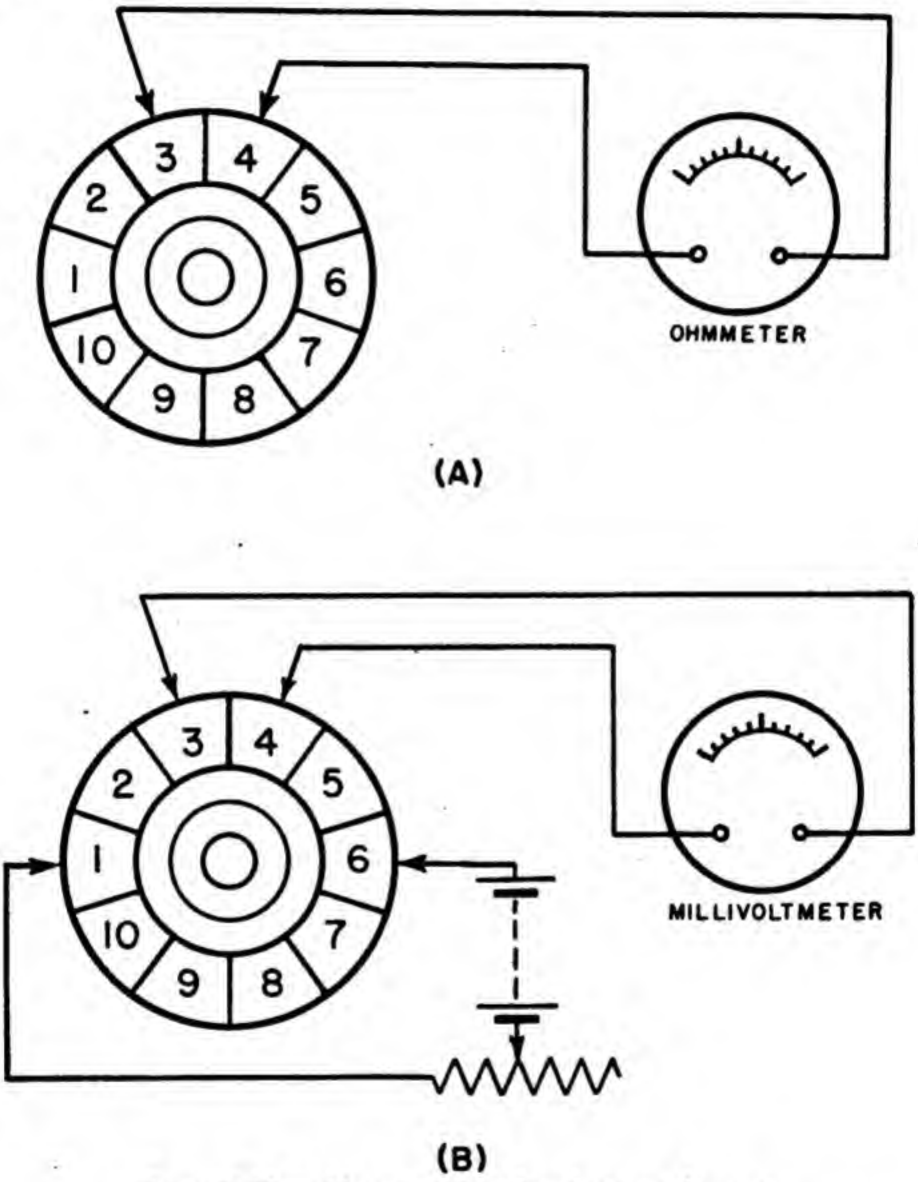


Figure 109.—Ohmmeter test for shorts and opens.

The method of connecting an ohmmeter in order to determine armature faults is shown in figure 109. The ohmmeter is connected directly across adjacent commutator bars. The test is repeated across adjacent segments over the entire commu-

tator. A low reading betwen any two segments indicates a shorted coil attached to these segments. A high reading denotes an OPEN.

If battery voltage is applied across segments on opposite sides of the commutator, a current will pass through the windings. Because the armature is symmetrical, there will be two paths for current. Furthermore, if the coils are of equal resistance (as they should be), the voltage drops across adjacent segments of the commutator are also equal. A millivoltmeter also should give the same reading when placed across any two adjacent segments of the commutator. If an armature coil is shorted, the resistance between segments attached to the ends of the this coil is less. Also, the voltage drop across the segments is less.

If a coil is OPEN, only one path for armature current exists. Refer to figure 109*B*. The millivoltmeter, instead of being connected across one loop, is connected through the loops of segments numbered 1, 2, and 3 to the brush at the left. The connection is through the loops of segments numbered 4, 5, and 6 to the brush at the right. Consequently, the millivoltmeter reading is higher. It indicates the voltage drop across the entire armature instead of the drop across the loop. And so again, a high reading indicates an OPEN and a low reading indicates a SHORT. If the millivoltmeter is placed across segments 4 and 5, no reading is obtained because no current flows in this coil. The same is true for the other coils on this side of the armature when the meter does not complete the circuit.

The GROWLER is a device widely used in repair shops to localize trouble quickly in generator and motor armatures. Essentially it is an electromagnet with a V-shaped opening in the core. This type of opening makes it possible to place

various sized armatures in the gap. The electromagnet is energized from an a-c source. The armature under test is placed in the gap. The resulting relatively loud hum gives the growler its name.

An end view of an armature under test in a growler is given in figure 110. When the growler

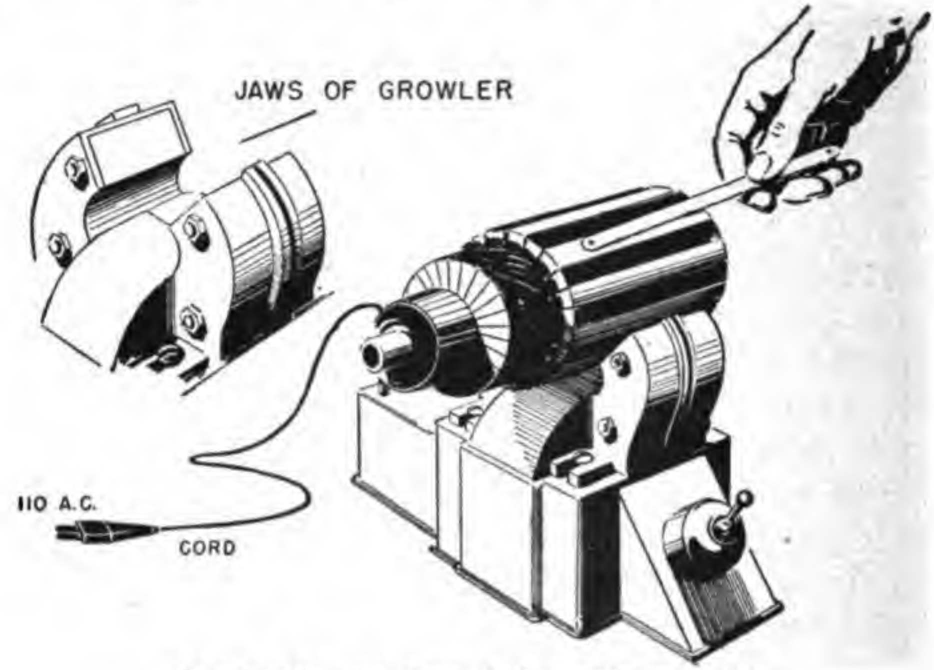


Figure 110.—Armature testing with a growler.

is energized, a changing magnetic field is produced which cuts the coils of the armature. As the field collapses and expands, transformer action takes place and induces a voltage in the armature coils. Several tests now can be made to determine a specific armature fault.

The presence of smoke immediately indicates faulty insulation at some point in the armature. Tests for shorts and open circuits are made by exploring the armature coil with a thin strip of iron or steel such as a hacksaw blade. Because the armature winding is symmetrical, the hacksaw blade is attracted with equal force at any point on the surface of the rotor. If an armature coil is

shorted, a large induced current flows in the coil. The hacksaw blade is attracted more strongly when placed over the coil. On the other hand, an open coil has no induced current. At this point the attraction of the armature for the hacksaw blade is weak.

The circuits used in testing a field coil for grounds are the same as those used for ground

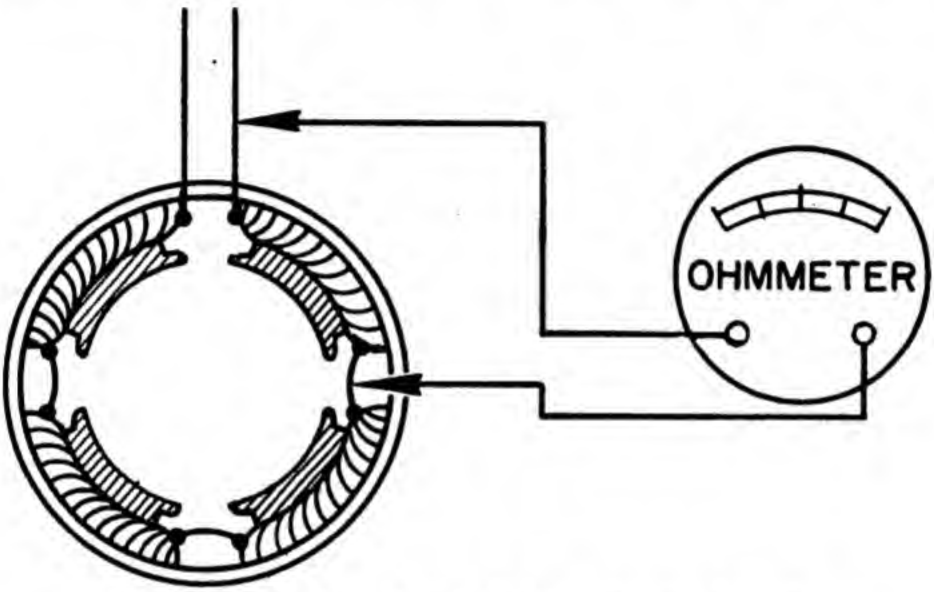


Figure 111.—Testing a field winding using an ohmmeter.

testing an armature. They differ only in the points at which the test is applied. In the armature, the test points were the armature core and the commutator. Test points in the field are the field terminal and the generator housing. Before applying the test, trace the field circuit in order to determine whether or not the field is grounded intentionally at one point. If such is the case, REMOVE THE GROUND.

Tests for open circuits or shorts in the field windings of a motor or generator are made by comparing the resistance of one section of the field with that of the other sections, or by comparison of the relative voltage drop in the sections.

In either method, the readings obtained across any one section of the field approximate those obtained across any other section.

The manner in which an ohmmeter is connected for a resistance test is shown in figure 111. Should the resistance of any one section exceed greatly

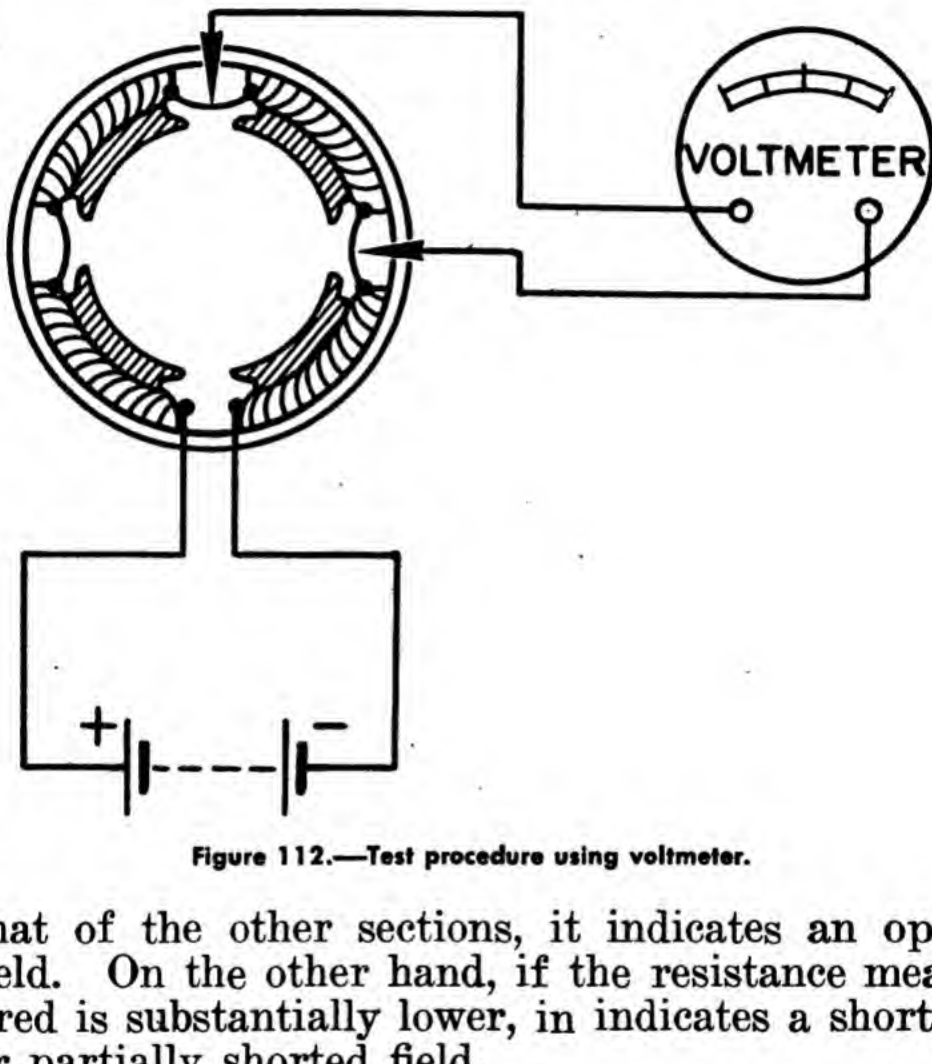


Figure 112.—Test procedure using voltmeter.

that of the other sections, it indicates an open field. On the other hand, if the resistance measured is substantially lower, in indicates a shorted or partially shorted field.

Figure 112 shows a circuit used for comparing the voltage drop across the sections of a field circuit. The voltage drop across each field section should be equal to the applied voltage divided by the number of field sections. A voltmeter should indicate the same reading when placed across each section. A comparable decrease in voltage-drop

indicates a short circuit. An increase indicates an open circuit.

RESIDUAL MAGNETISM

The field poles in an aircraft generator are lightly constructed. Consequently, they often loose their residual magnetism if they are allowed to stand idle. The poles also lose residual magnetism if they are subjected to mechanical shock in landing. Careless handling during disassembly and repair also may cause the loss. Without residual magnetism, a self-excited generator cannot build up voltage when rotated.

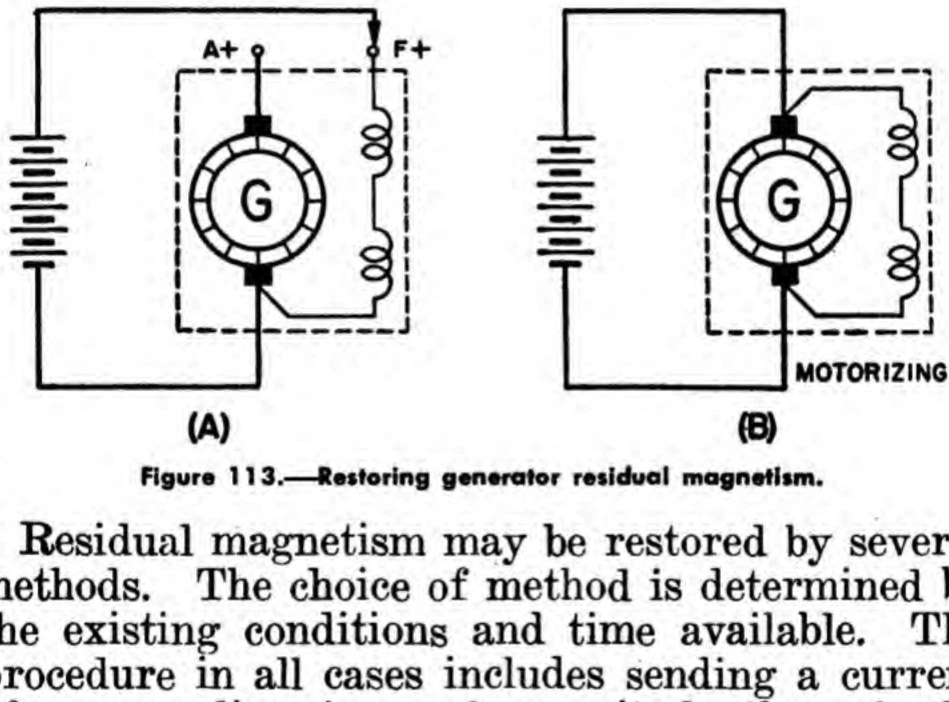


Figure 113.—Restoring generator residual magnetism.

Residual magnetism may be restored by several methods. The choice of method is determined by the existing conditions and time available. The procedure in all cases includes sending a current of proper direction and magnitude through the field windings. This operation is called FLASHING THE FIELD.

If the generator is in the shop for inspection, test, or repair, restoration of residual magnetism is easily accomplished. In figure 113*A* a battery is shown connected to the field terminals of the generator. The current that flows in the field sets up normal field flux. If the battery is then dis-

connected, the magnetic field strength drops to the residual value.

A residual field is established regardless of the direction of current through the field winding. The electrical polarity of the generator is determined by the direction of the residual field. Hence, it is important to excite the field in the proper direction. To do this, the brush polarity must be known before excitation voltage is applied.

Knowing the brush polarity, the positive battery terminal is connected to the field terminal which, under normal operating conditions, is connected to the positive generator brush. Current then flows in the field in the same direction as it goes in actual practice. In this operation, field current need flow only for a short time. A few seconds generally suffice.

In all cases it is desirable to send current through the field circuit only. Because all aircraft generators are used with voltage regulators, the field terminal of the regulated field winding is usually available for connection. In this case, it is not necessary to disconnect the armature from the field. (See fig. 113*A*.)

In generators not primarily made for aircraft use, the field connects directly to the armature within the machine. With this type, it is conventional practice to flash the field by connecting a battery across the generator terminals (brushed). Because current flows in both armature and field, the generator rotates because of motor action. This procedure is known as MOTORIZING the generator. (See fig. 113*B*.) In this operation the rotation is of no practical importance, since it is the current flowing in the field circuit that restores the residual magnetism. The direction of current through the field is very im-

portant because of its effect on the electrical polarity of the brushes. It is absolutely necessary to remember that the positive terminal of the battery must be connected to the generator terminal which is to be positive when the unit is finally installed in the plane.

When a generator loses residual magnetism after installation in an airplane, it would be a waste of time and effort to remove it from the airplane. It is a relatively easy matter to flash the field while the unit is still in place. Certain precautions must be observed.

In the shop, a battery is used to restore residual magnetism by motorizing the generator or flashing the field only. In an airplane, the main battery is connected to the generator through the cut-out relay and the battery can therefore be used for field excitation.

The quickest way to do this is to close the cut-out relay by hand, connecting the battery directly to both field and armature of the generator. This procedure seems the equivalent of motorizing the generator—as occurs in shop practice. Actually, it is not so. In a shop test the armature can rotate freely. In an airplane, the generator is geared to the engine and cannot rotate unless it drives the engine. Because a generator operating as a motor does not have sufficient torque, the armature is held in position. When the armature is held in place it cannot develop counter-emf. Under the condition, the armature current is high, and the powerful armature current leads to complications.

This entire operation is performed in order to restore residual magnetism to the field poles. Current flows in both armature and field circuits and each unit builds up its own magnetic field. The field flux produced by the field current is in

the right direction, but it is opposed by the powerful magnetic field produced by the relatively strong armature current. The armature uses the entire field structure as a path for armature flux.

When the cut-out relay points are opened, the field poles are left with residual magnetism established by armature current and not by field current. The result is a residual magnetic field of incorrect polarity.

Logically the next operation is to test the generator by driving it with the engine. When this is done, voltage build-up occurs but with incorrect electrical polarity of the generator terminals. If the cut-out relay is not polarized, its contacts close even with incorrect generator polarity. This connects the generator and battery together. The result is a short circuit on both units.

The reversal of polarity MUST NOT OCCUR. The remedy is a simple one. The armature circuit must be opened whenever the field is to be flashed, thus eliminating the armature magnetic field.

The armature circuit is opened by insulating the brush from the armature, accomplished by placing a piece of paper under the brush. In a two-brush generator unit only one brush is insulated. In a four-brush unit either the positive or negative set of brushes is insulated. (See fig. 114.) This method of insulating the brushes is rather tedious and time-consuming.

The easiest and safest method is to disconnect the $A+$ lead from the generator at the generator control box. In certain installations, this is not possible because the $A+$ lead is welded to the terminals and cannot be disconnected unless the plug containing the field leads is also removed. With such an installation it is necessary to insu-

late the brush OR to use the method described in the following paragraph.

It is possible to flash a generator field while the generator is being driven at normal speed by the engine. If no residual field is present, there will be no generator voltage at any speed. If the cut-out relay is then closed by hand, the

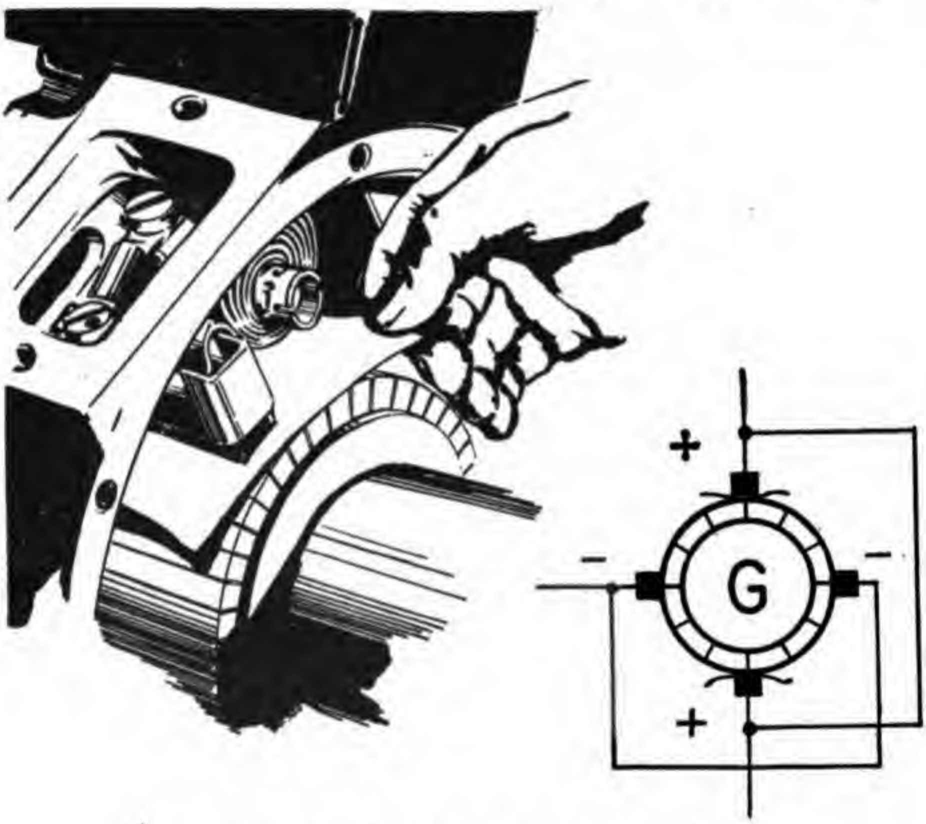
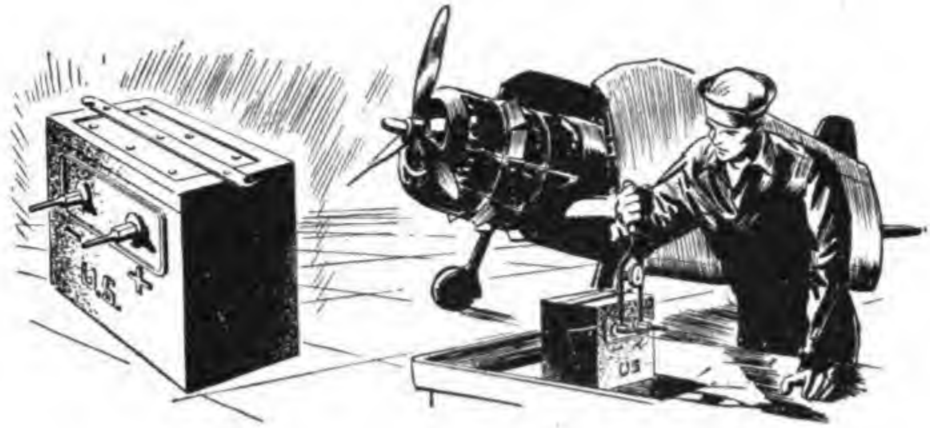


Figure 114.—Insulating generator brushes.

armature current cannot reach the high value obtained when the armature is at a standstill. As a result, field current, and not armature current, will produce field flux. In other words, reversal of generator electrical polarity is not so likely to occur if the cut-out points are manually closed during rotation of the generator armature.



CHAPTER 12

THE STORAGE BATTERY

EXTRA INSURANCE

Your last night of leave, and your last chance to show the girl friend the town. But ALL your money is gone. Then you suddenly remember the TEN SPOT you salted away. What a feeling of RELIEF!

Well, the storage battery in the airplane is that extra $10 that you salted away. It provides the aircraft electrical system with protection. The total connected load, exclusive of main-engine cranking current, usually is so great that the battery has only sufficient capacity to carry this load for a few minutes. Except in certain primary trainer types, aircraft are provided with generators. While on flight the battery is required to carry only sudden peak loads in excess of generator capacity. These peak loads are usually of short duration.

In view of the exacting weight limitations imposed on aircraft batteries, their capacity must necessarily be sufficient to meet all transient and combat flight demands which cannot be handled by the generator. They are not large enough to

supply power for ground operations. It has been reported that 90 percent of the discharged batteries brought into the Naval shops for charging were RUN DOWN on the ground.

It is undesirable to use the battery for starting main engines. Almost all fighter airplanes are equipped with cartridge starters, and most patrol bombers are equipped with auxiliary power units. These units may be started first, thereby supplying power for starting the main engines. The great majority of Naval aircraft have starters which can be cranked by external energizers.

Several types of Army airplanes are equipped with external plugs to permit starting them with battery carts or other external power supply. For these, Recto starters operating on 110 volts a. c. and supplying either 24 or 12 volts d. c. are used. In the future, Navy aircraft will be wired to accommodate external power for starting. Some stations have already built battery carts for starting purposes. These carts sometimes are equipped with gasoline-driven generators or other portable charging equipment. The new 26-hp Waukesha gasoline motor (when equipped with a standard aircraft generator, voltage regulator, cut-out, voltmeter, two AN3152 batteries, and mounted on a dolly) are useful for starting operations.

The aircraft storage battery should not be used for any ground-testing operations. Even relatively small radio equipment draws sufficient current to discharge the aircraft storage battery completely in a short time. The load drawn by turrets is considerably greater than the ratio load. All ground activities should have external power supply equipment for testing radio, radar, turret, and other accessories. Equipment used for ground testing is of the following types—

Onan motor-generator, operating from 200-volt, 3-phase motor which provides 1,200 watts of 800 cycles, 120-volt a-c current and 18 amperes of 24-volt d-c current.

Onan gasoline-driven generator with the same output.

Lincoln arc welder with necessary drawings and conversion parts to provide 200 amperes of 24-volt, d-c current which operates from 220-volt, 3-phase power supply.

The 26-hp Waukesha gasoline engine which uses standard round-flange aircraft generators and generator control equipment.

With specific gravity adjusted to 1.280 at 80° F., the average open-circuit voltage of a fully charged cell is approximately 2.10 volts. This varies with temperature.

The voltage of the cell during discharge will be less than the open circuit reading and will vary with the rate of discharge. It reaches a minimum value when the cell is completely discharged. Storage battery capacity ratings usually are based on final cell voltages of 1.75 volts, when the battery is discharged at its 5-hour rating. The capacity rating is based on 1.20 volts when the battery is discharged at its 5-minute rating.

Cell voltage readings during charge are always higher than the open circuit readings. The reason for this variance is that the voltage on charge actually is the pressure required to force the charging current through the cell. The value of the voltage depends on the charging current and the counter-voltage of the cell. Counter-voltage varies with the state of discharge. As a cell approaches a state of full charge, its counter-voltage gradually increases.

In order to maintain the charging current at a constant value, higher impressed voltages are required. The voltage across a cell during charge is about 2 to 2.05 volts at the start of charge, but increases to 2.40 or 2.65 volts at the end of charge. No further rise in cell voltage occurs after the cell has been brought to a 100-percent charged state. The voltages observed on charge vary with the charge rates, temperature, and somewhat with the age of the battery.

The most important consideration in the maintenance of aircraft batteries is the voltage applied to them for charging purposes in that aircraft. The exact value at which the generator voltage regulator should be set varies with the average operating temperature of the battery. There should be a balance between the amount the battery is discharged and the amount it is charged.

If insufficient charge is given, the battery will become discharged. When too great a charge is given, an excessive amount of water is used and unnecessary wear on the plates occurs. If excessively high voltage is used, violent gassing and heating of the battery are the results. Some cases have been reported in which a battery exploded.

The voltage of a battery on charge varies INVERSELY with its temperature. The regulators controlling the generator voltage are compensated for temperature. They provide a fairly constant voltage throughout ordinary temperature ranges. Storage batteries, however, require lower generator voltages at higher battery temperatures, and higher generator voltages at lower battery temperatures.

A generator voltage regulator, capable of varying its operating voltage, compensates for changes in battery temperatures. In adjusting a regulator, the average temperature under which the

battery normally operates must be the governing factor. Temperature may change considerably while in flight because of change in location (altitudes). Unless temperature changes are considered when the generator regulator is adjusted, the battery will not operate satisfactorily.

The charging rate of the storage battery should TAPER OFF as the battery approaches full charge. With the voltage regulator set properly, the tapering effect is automatic. The difference in generator voltage and battery voltage forces current through the battery to charge it. Therefore, as the battery comes up to full charge, its voltage also rises slightly. Hence, the difference in the generator voltage and battery voltage becomes less and less. This results in a TAPERING CHARGING RATE.

Aircraft generators usually have ample capacity for providing the maximum desirable charging currents. High-voltage regulator settings or failure to adjust regulators properly cause extremely high charging rates which result in battery failure.

The following table shows the voltages for which the generator voltage regulator should be adjusted for different battery operating temperatures—

Battery temperature	Generator voltage regulator settings	
	(6-cell batteries)	(12-cell batteries)
	Volts	*Volts*
Above 90° F	13. 50 to 13. 75	27. 0 to 27. 5
40° to 90° F	13. 75 to 14. 0	27. 5 to 28. 0
Below 40° F	14. 25 to 14. 75	28. 5 to 29. 5

These generator voltages are critical and should be adhered to strictly. Practically all cases of extensive battery failure may be remedied by low-

ering the aircraft generator voltages to the figures listed in the table.

In the last year rapid strides have been made in constructing voltage regulators which produce satisfactory adjustments of the generator under all conditions of load and rpm. The old vibrator-type regulator and finger-type regulators are being supplanted by carbon-pile regulators. Their use will be of material assistance to squadron personnel in keeping bus voltage constant. Consequently, they help to keep the batteries in operation.

Before a battery is installed in an airplane, each cell should be checked carefully to make sure that it is fully charged (hydrometer reading). The solution level in each cell should not be too high. The top of the battery should be dry and clean.

The hold-down devices should be properly secured so that the battery cannot possibly break loose when in flight. Wing nuts provided for this purpose should be finger-tight. Tightening them with a wrench or with pliers springs the cover of the battery and makes it nonliquid tight.

During flight the generator will charge the battery, maintaining a near full-charge condition. If at the end of flight the hydrometer reading of a 1062–11 battery is below 1.240, the battery should be removed for a bench charge. All other batteries should be removed if the specific gravity is below 1.220.

If the battery is uncomfortably warm to the touch, check the generator voltage-regulator setting. With no load and the generator up to speed, the aircraft bus voltage should be within specified limits. If the voltage regulator setting is too high, charging rates are higher than the battery can safely absorb. This causes the battery to heat and gas violently.

If the battery becomes discharged during flight and there is no evidence of broken leads or other structural difficulties, check the generator, voltage regulator, cut-out, or the battery itself in order to find out the cause of the discharge. If the generator voltage is normal, the run-down battery may be caused by the failure of the reverse current relay to remain closed. CHECK IT. If necessary, the relay may be held shut by mechanical means during flight. But it should be checked and reset at the first opportunity.

The voltage regulator may be at fault if the generator voltage is low. The regulator should be checked and reset as soon as possible.

The battery may be shorted internally or have failed structurally. These are not likely causes of failure if the battery was checked before flight, and was found to be giving satisfactory voltage.

It is important to determine the condition of the battery at the end of each flight. Complete inspection of the battery on certain types of aircraft cannot be accomplished effectively without removing the battery from its compartment. In some installations the time required for this operation is prohibitive. Inspection of the following items, however, must be made—

HOLD-DOWN DEVICES—Make sure that the battery is securely mounted in its compartment.

BATTERY LEADS for the condition of the insulation.

OUTSIDE OF THE BATTERY CONTAINER for evidence of leakage.

OPEN CIRCUIT VOLTAGE—If it is below 12 volts for a 6-cell battery, and 24 volts for a 12-cell battery, immediately remove battery for recharge.

HOT BATTERIES, or batteries consuming water at an unusually rapid rate, are evidences of excessive charging rates, which occur when the generator-voltage regulator is set too high, or from low battery voltage. Low battery voltage may be caused by high battery temperatures resulting from overheating. Occasionally the battery heats abnormally or shows evidence of low capacity—even though the generator-voltage regulator is adjusted properly. When such conditions are present, the battery should be removed for repairs.

STANDARD BATTERY INSPECTION

At weekly intervals, or immediately after a complaint from a pilot, a battery must be thoroughly inspected. If it is necessary, remove the battery from its compartment. The following conditions must be carefully determined.

Test the SPECIFIC GRAVITY of each cell with an accurate hydrometer, returning the electrolyte to the cell from which it was removed. Record the specific gravity and temperature of the cells having the highest and lowest specific gravity readings. In case the specific gravity of the lowest cell is below 1.240 with the 1062–11 battery or 1.220 with other aircraft batteries (temperature corrected to 80° F.), remove the battery for recharge. Replace it with a fully charged battery. If the difference in specific gravity between the highest and lowest cell is 30 points or more, remove the battery for repairs.

Wash and clean HYDROMETER BARRELS frequently. Do not take hydrometer readings immediately after adding water. Wait until after a flight for the water to have been mixed with the electrolyte. If the battery

is on charge in the shop, and gassing, the water will be mixed within an hour.

DO NOT SAMPLE THE SAME CELL EACH TIME. This procedure lowers the gravity of the cell through continued loss of small amounts of electrolyte. Sampling all cells disperses the possible loss throughout the cells.

CHECK THE SOLUTION in each cell. It may be necessary to add approved water to the correct height. Use a self-leveling filling syringe. Be careful that the solution level is not more than one-half inch above the protector in the cell. If too much water is accidentally put into the cell, immediately withdraw the solution level to the correct height. A suitable self-leveling syringe can be prepared by drilling a hole one thirty-second inch in diameter in the stem of a standard hard rubber syringe, one-half inch from the tip.

Carefully examine the TOP OF THE BATTERY AND SEALING COMPOUND for evidence of leakage. If any evidence is found, remove battery for necessary repairs.

See that the battery is clean and dry. Neutralize acid or moisture on the top of the battery by using a solution of bicarbonate of soda and water. Do NOT get any of the soda solution into the cells.

Inspect the BATTERY TERMINALS for evidence of corrosion. Carefully scrape off any corrosion and neutralize the spot with a soda solution. Dry the surface thoroughly and coat the affected parts with vaseline before reconnecting the battery in the aircraft.

Examine the STUDS running through the aluminum container which connect the cell ter-

minals with the battery terminals, for evidence of corrosion.

OPEN THE CONNECTIONS so that corrosion between the studs and the aluminum containers may be removed and neutralized with a soda solution. Coat affected parts with vaseline before reassembling.

CHECK carefully THE ALUMINUM CONTAINER for evidence of acid leakage from a hole or crack in the container and for acid coming over the top of the container. If the aluminum container is found leaking, the battery should be removed for repairs. If the cover seal is defective, necessary repairs should be made.

When an aircraft battery is to REMAIN IDLE for more than 1 week, it should BE REMOVED and TURNED in to the battery room for storage and necessary servicing.